

Environmental Control Technology Survey of Selected U.S. Strip Mining Sites

Water Quality Impacts and Overburden Chemistry
of Southern Illinois Study Site IL-2

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ENVIRONMENTAL CONTROL TECHNOLOGY
SURVEY OF SELECTED U.S. STRIP MINING SITES

Water Quality Impacts and Overburden
Chemistry of Southern Illinois Study Site IL-2

by

William C. Hood
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for

Argonne National Laboratory
Energy and Environmental Systems Division
Environmental Control Technology Program

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FOREWORD

The Argonne National Laboratory (ANL) program entitled "Environmental Control Technology Survey of Selected U.S. Strip Mining Sites" is being funded by the U.S. Department of Energy (DOE). The program was established in 1975 by an interagency agreement between DOE's precursor -- the U.S. Energy Research and Development Administration -- and the U.S. Environmental Protection Agency (EPA).

This program has a twofold purpose which is related in part to the interests of its two federal sponsors. The overall issue addressed by both sponsors is the need to satisfy increased coal demand in an environmentally acceptable manner. Each sponsor, however, has particular interests: DOE is interested in the efficacy and practicability of coal mine effluent control options currently in use, an identification of control technology problems and needs, and recommendations for research in these areas; the EPA was interested in an assessment of the validity of its effluent limitations guidelines and new source performance standards for the coal mining industry, with this assessment emphasizing seasonal and climatic variation impacts on effluent quantity and quality. A program plan was outlined to (1) project future coal production levels to the year 2000 as a basis for selection of case study mines, (2) gather data on effluent volumes and characteristics at surface mine case study mines, (3) examine the efficacy and economics of current effluent-control systems (treatment facilities and settling ponds), (4) assess the validity of the effluent guidelines, and (5) evaluate potential environmental impacts related to increased surface mining.

Summaries of the program's various aspects are being published in several volumes. Water quality data gathered at the case-study sites are analyzed in terms of potential local impacts in Argonne report ANL/EMR-2, Volumes 2A-2C, and in several reports in the ANL/EES-TM- series. This report (included in the latter series) is being published essentially as received (i.e., with only minimal revision) from the author-consultant named on the title page. All sites were coded using state abbreviations in order to protect the identity of individual mines. In ANL/EMR-2, Volume 3, the efficacy and economics of the various types of control technologies are examined, along with physical and chemical characteristics of treatment waste products. Report ANL/EMR-2, Volume 4, contains an assessment of the EPA effluent limitations guidelines (and those of the U.S. Dept. of Interior's Office of Surface Mining) for the coal mining industry relative to the data collected under this program. Thus, this entire set of reports examines the efficacy of various control technology options and assesses the potential environmental impacts related to increased surface mining based on detailed case-study site data.

ENVIRONMENTAL CONTROL TECHNOLOGY
SURVEY OF SELECTED U.S. STRIP MINING SITES

Water Quality Impacts and Overburden
Chemistry of Southern Illinois Study Site IL-2

William C. Hood

ABSTRACT

As part of a program to examine the ability of existing control technologies to meet proposed federal guidelines for the quality of aqueous effluents from coal mines, intensive studies of water, coal, and overburden chemistry were conducted at a surface mine in southern Illinois in 1976-1977. Water sampling sites at the mine (designated IL-2) included several points on the receiving stream (for mine effluent), a tributary to the receiving stream, and intake and discharge water for a coal cleaning plant. No chemical treatment for mine drainage or settling ponds was used at this mine during the course of the study. Water quality data for parameters included in the federal regulations generally indicated a sharp contrast between water in the mined area and water in the coal cleaning plant area. The latter consisted of a closed circuit with makeup intake water originating in a drainage basin that has historically received untreated and treated mine drainage. Water in the mined area generally complied with federal standards for pH, iron, manganese, and total suspended solids, while water in the coal cleaning plant circuit occasionally did not comply. Seasonal trends for regulated water quality parameters, based on sampling every two weeks, were not evident. Overburden analysis indicated that for most lithologic units, neutralization potential exceeded acid potential; the only exceptions were for the coal itself and a thin carbonaceous siltstone overlying the coal.

1 INTRODUCTION

The coal-producing area of southern Illinois is a portion of the Eastern Region of the Interior Coal Province (Figure 1). Along the outcrop area of Pennsylvanian-age rocks stretching across the southern third of the state are some of the more important counties in terms of coal production. Perry, Williamson, and Saline Counties have each produced more than 225 million tons of coal since 1882, with much of the production coming from surface mining. This study focused on a surface mine in this three-county area that is reasonably representative of mines in the eastern part of the southern Illinois area.

1.1 MINE SELECTION

The main factors in the selection of this mine as a site for the study were (1) Argonne's desire to have a site in the eastern part of the southern Illinois area and (2) the author's familiarity with the mine through other projects at the mine and nearby areas. The study began in March 1976 with a visit to the mine and selection of potential sampling sites. These sites were described by telephone to Dr. Donald Johnson of Argonne to obtain his concurrence as to their suitability and were then cleared with the company. The actual water monitoring began in April 1976. Sampling was continued every two weeks until July 1977, except for a period during late December and January 1977 when severe weather froze the streams.

1.2 IDENTIFICATION OF SITE

The mine under study, which has been designated as Mine IL-2, is located in the Illinois Coal Field, specifically within the Southern Producing District (Keystone Coal Manual designation).

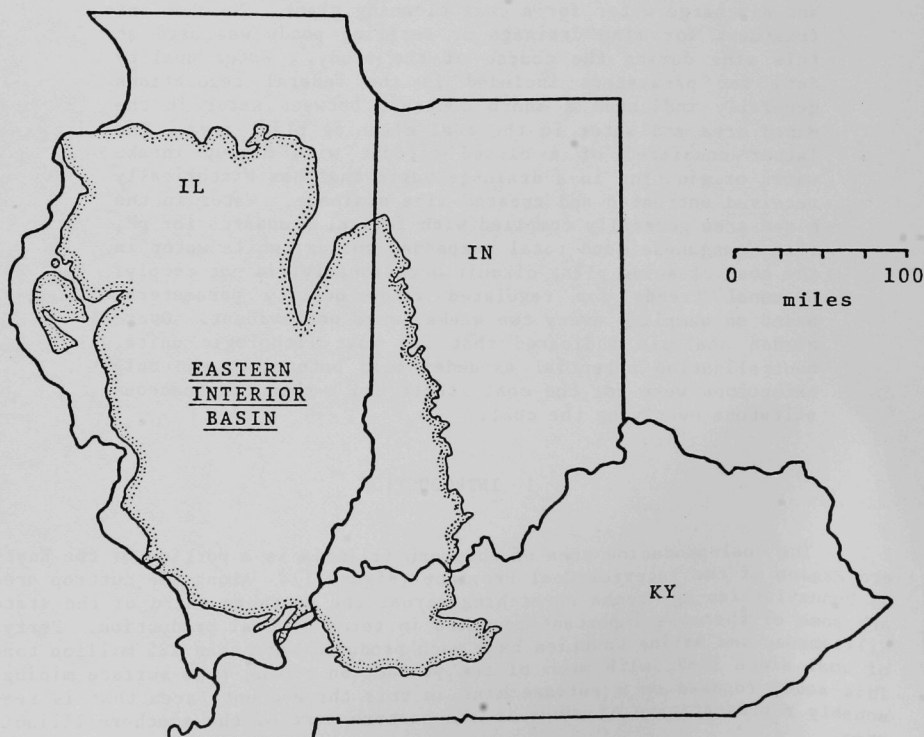


Fig. 1 Eastern Interior Basin in Illinois, Indiana, and Kentucky

2 NATURAL SETTING

2.1 PHYSIOGRAPHY AND TOPOGRAPHY

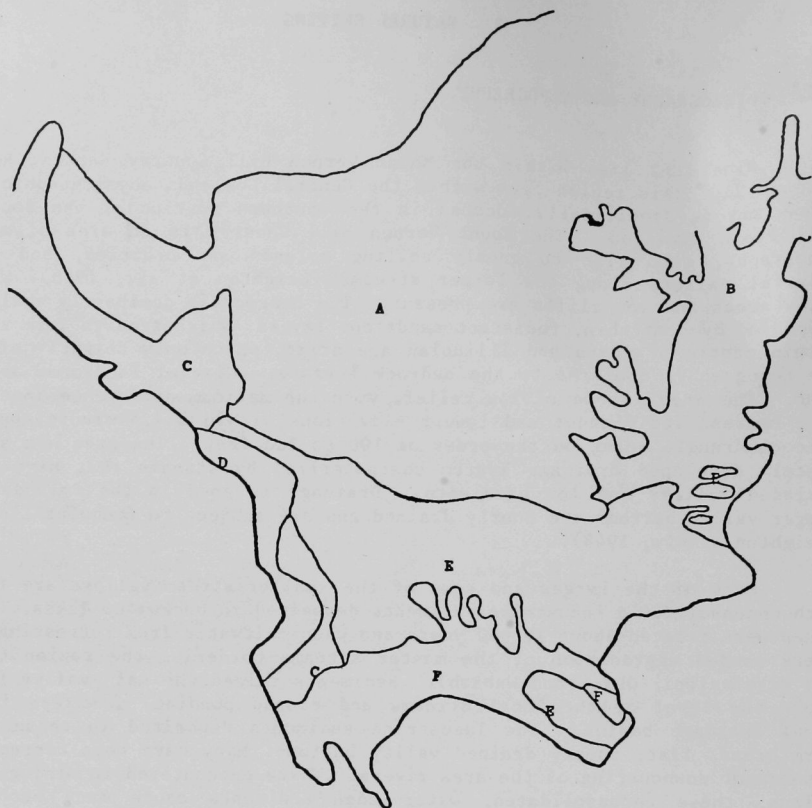
Mine IL-2 lies within the Mount Vernon Hill Country Natural Region (Figure 2). This region lies within the Central Lowlands physiographic province and is specifically located in the southern portion of the Southern Till Plain division. The Mount Vernon Hill Country is an area of mature topography, with flat to gently rolling uplands and prairies, and broad alluvial valleys along the larger streams (Leighton et al., 1948). Wooded hilly areas and low cliffs are present. The bedrock is dominantly shale accompanied by some thin, resistant sandstone layers which tend to form ridges. A thin mantle of loess and Illinoian age drift, which only slightly affects the topography, conforms to the bedrock surface. Glacial landforms are absent. The area is one of low relief, with the maximum difference in elevation between the highest and lowest elevations within a 7.5-minute topographic quadrangle being on the order of 100 to 200 feet. The area has a completely developed drainage system characterized by streams that have broad terraced valleys and low gradients. Drainage is good in the uplands, but larger valley bottoms are poorly drained and are subject to frequent flooding (Leighton et al., 1948).

Many of the larger and some of the smaller stream valleys are filled with unconsolidated lacustrine sediments deposited in backwater lakes. These lakes were created about 20,000 years ago when meltwater from retreating glaciers caused aggradation of the master streams bordering the region (i.e., the Mississippi, Ohio, and Wabash). Sediments raised the main valley floors above the level of the local streams and caused ponding of waters in the local drainage basins. The lacustrine sediments deposited in these lakes form broad, flat, poorly drained valley bottoms. Many have been terraced by subsequent downcutting of the area rivers. Where encountered in mining operations, these unconsolidated, water-laden sediments cause many problems.

In the immediate vicinity of the mine, the average surface elevation is on the order of 500 feet above mean sea level. The overall relief in the area in which mining has occurred over the past 15 or so years is on the order of 90 feet; however, relief along the highwall at any one time is no more than 40 feet. Slopes of the valley sides are on the order of 5%, and overall slopes of the rolling uplands are less than this.

2.2 CLIMATE

The climate of the southern Illinois region is typically continental. It has cold winters and warm summers, both characterized by frequent fluctuations of temperature, cloud cover, etc. Because no natural barriers intervene, the area encounters the full sweep of winds bringing in weather typical of other areas. Southerly and southwesterly winds bring warm, showery weather up from the Gulf of Mexico, whereas northwesterly winds bring cool, drier weather. Weather fronts generally pass eastward or northeastward through the area.



- A Mount Vernon Hill Country Section of the Southern Till Plain Section
- B Wabash Border Division
- C Ozark Division
- D Lower Mississippi River Bottomlands Division
- E Shawnee Hills Division
- F Coastal Plain Division

Fig. 2 Natural Regions of Southern Illinois

Precipitation tends to be widespread over the region during fall, winter and spring; however, summer rainfall typically occurs as localized showers which may be of high intensity. Only three or four days of snowfall exceeding one inch will occur in a typical winter, and the ground is covered with an inch or more of snowfall less than 15 days per year.

Figure 3 shows the seasonal distribution of temperatures and precipitation at a weather station several miles from Mine IL-2. Mean monthly temperatures range from about 35°F in January to about 78°F in July. Mean annual temperature is 57°F. Monthly precipitation is fairly uniform, varying from slightly over 3 inches in October to 4.8 inches in May (Figure 3). Spring tends to be the wettest season and summer and early autumn the driest period. Annual precipitation averages 46.8 inches.

Rainfall at the weather station during the study period is given in Table 1 and is shown diagrammatically in Figure 4.

2.3 GENERAL GEOLOGY

Mine IL-2 is located near the south edge of the Illinois Basin, a major subdivision of the Eastern Interior Coal Basin (Figure 1). The deepest part of this basin is located close to the point where Illinois, Indiana, and Kentucky join, but the geographic center is located northwest of this point. In general, rocks along the southern edge of the basin tend to dip northward to northeastward toward the center of the basin. In the mine area the dip is about one degree toward the north. This results in a stratigraphic sequence of successively younger rocks going from south to north in the area.

Several large fault zones disturb this simple picture in southern Illinois. However, with one exception, faults do not appreciably disturb the Pennsylvanian rocks in the coal-producing counties. The one exception is the Shawneetown-Rough Creek fault zone, located in Gallatin and southeastern Saline counties. The fault itself is a high-angle reverse fault (Ross, 1963), and displacement may reach 3600 feet (Wilson, 1959).

Two other major structural features disrupt the coal-bearing rocks in the producing areas and merit description. These are the Eagle Valley Syncline and the DuQuoin Monocline.

The westward trending Eagle Valley Syncline (also called Eagle Creek Syncline) is on the eastern side of Illinois, mainly in Gallatin County but also extending westward into Saline and southward into Hardin counties. Pennsylvanian age rocks are strongly folded into a narrow syncline which reverses the usual northward dip of the rocks. On the south limb, the rocks dip less than 5 degrees to the north, and on the north limb the dip is as much as 25 degrees to the south. The syncline is bounded on the north by the Shawneetown-Rough Creek fault zone.

The DuQuoin Monocline is located where the eastern edges of Jackson, Perry and Washington counties adjoin the western edges of Jefferson and Franklin counties. This east-facing, north-south trending structure drops

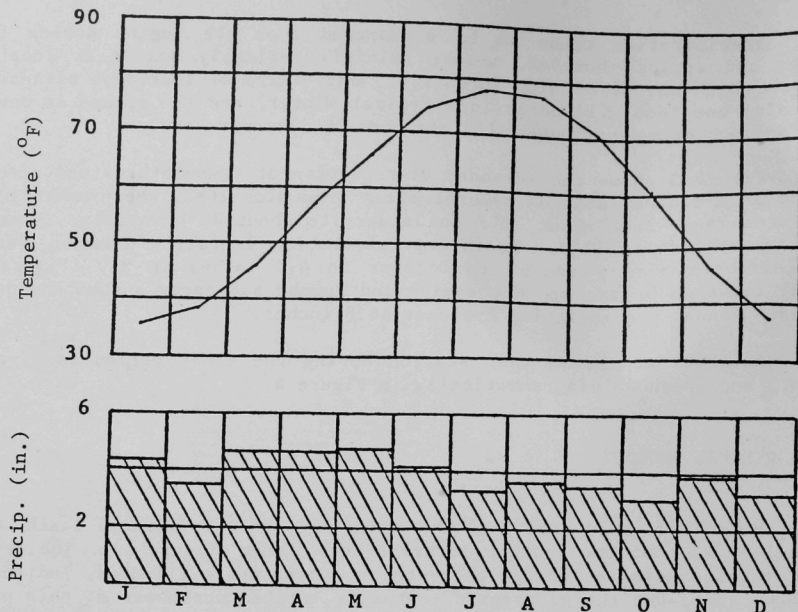


Fig. 3 Average Monthly Rainfall and Temperature at a Weather Station near Mine IL-2 (data from Denmark, 1974)

on the eastern side by more than 200 hundred feet. The DuQuoin Monocline strongly affects the thickness of the Pennsylvanian rocks that cross it, so it appears to have been active during Pennsylvanian time, separating a more stable western shelf area from a more rapidly subsiding basin (Fairfield basin) to the east.

The coal-bearing rocks of Illinois are Pennsylvanian in age, with most of the coal occurring in rocks of Middle Pennsylvanian age. Total thickness of the Pennsylvanian section in southern Illinois ranges from about 1500 feet in Perry, Randolph, and Jackson counties to about 2500 feet in Gallatin, Williamson, and Saline counties. Several formations are currently recognized, and cyclic sedimentation patterns are present within each of them. The formations of interest in this report are, from oldest to youngest, Caseyville, Abbott, Spoon, Carbondale, and Modesto. The Caseyville and Abbott, which contain almost no coal, and the Modesto, which is not generally present in the overburden of the strip mines, will be dealt with only briefly.

Caseyville Formation. In the western part of southern Illinois, i.e., St. Clair, Randolph, western Perry, and western Jackson counties, the Caseyville rocks are either thin or absent. However, east of the DuQuoin Monocline (i.e., eastern Perry and Jackson counties and further east), Caseyville rocks can reach thicknesses of 300 to 400 feet and occasionally more than 500 feet.

Table 1 Precipitation Data for a Weather Station near Mine IL-2

Day	1976							1977								
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1			0.41		0.65	0.06										0.70
2		0.10	0.15										0.22			
3		0.14	0.78	2.30						0.17		0.10	0.11	0.09		
4			0.40	0.89								1.38	0.06	0.22		
5			0.04							0.06		0.03	0.20	0.22		
6					0.14		0.37									
7		0.43							0.41	0.33					0.40	
8																
9						0.94	0.05			0.20					0.03	
10						0.51				0.54						0.23
11									0.48							0.33
12											0.20	1.34				0.01
13				0.06											0.02	
14		0.44								0.83						
15		0.15			0.18								0.70			
16		0.16	0.90	0.02	1.68					0.02						
17		0.54														
18		0.15								0.02		0.58				
19	0.32		0.38							0.03			0.12			
20	0.32						0.35			0.16	0.02	0.10	0.25			
21	0.47												0.07			
22												0.13	0.19			
23			1.30				0.55						1.36			
24			0.40				1.87			0.27	1.01		0.03	0.14	1.03	
25	1.48		0.94	0.12										0.15	0.18	
26			0.20			0.14		0.77			0.02			0.14	0.15	0.28
27				0.03		0.65		0.03			0.73	0.27			0.54	
28		0.91		0.35		0.05						7.25	0.12		0.30	
29	0.18	0.14	0.10	0.78					0.27			0.12			0.35	0.12
30			0.03	0.08			0.75							0.36		
31				0.88			0.24							0.16		

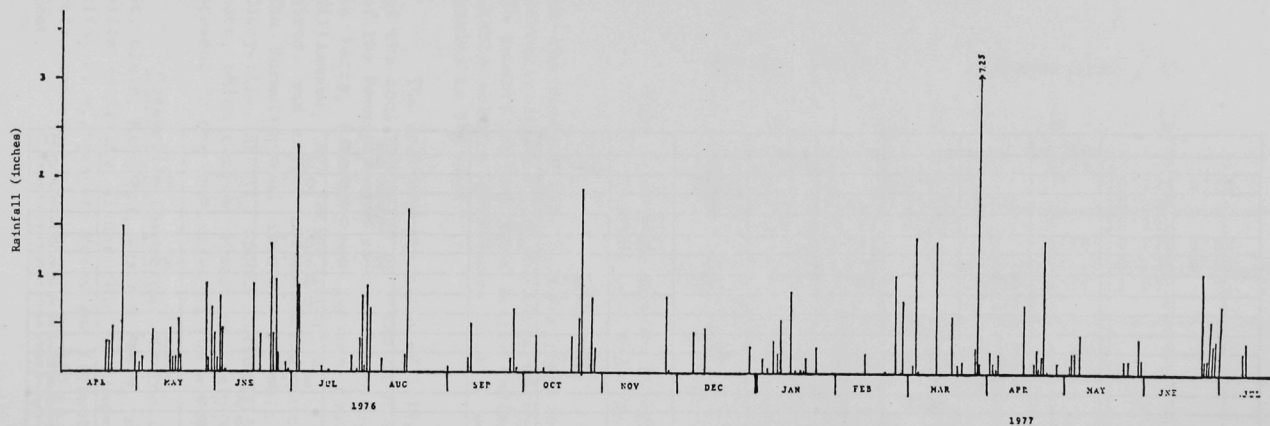


Fig. 4 Daily Rainfall at a Weather Station near Mine IL-2

The Caseyville Formation is dominated by clean, well-sorted quartz sandstones characterized by the presence of small white quartz pebbles. The sandstones, which make up more than 60% of the formation, are frequently channel-form and may attain thicknesses of over 100 feet. Cross-bedding is common in the channel facies. The sandstones, especially the thick channel facies, are resistant to erosion and form the prominent hills and cliffs of the Pennsylvanian escarpment in southern Illinois. The remaining portion of the formation consists of siltstone and silty or sandy shale. Limestone is virtually absent, and the rare coals are thin, lenticular, and discontinuous (Figure 5).

Abbott Formation. The Abbott Formation reaches a maximum thickness of about 350 feet in southeastern Illinois. It thins westward to about 50 feet west of the DuQuoin Monocline and eventually nearly thins out in the western part of the study area.

Lithologically, the Abbott Formation is similar to the Caseyville below it, with about half of the formation consisting of sandstone and half of shale (Figure 5). The sandstones are generally thinner, less well sorted, finer grained, and more micaceous than those of the Caseyville, and the small white pebbles that characterize Caseyville sandstone are absent in the Abbott. Shales of the Abbott are less sandy than those of the underlying Caseyville, and limestones are nearly absent. Coals are thicker and a little more persistent than in the Caseyville, but are not generally of economic importance.

Spoon Formation. The Spoon Formation is about 350 feet thick in southeastern Illinois and, like the underlying Abbott and Caseyville formations, thins toward the west, especially after crossing the DuQuoin Monocline, westward of which thicknesses are about 100 feet.

The lithology of the Spoon Formation is somewhat different from the underlying Abbott and Caseyville formations (Figure 5). The shales contain less sand and silt than those of the underlying formations. Sandstones of the formation are not markedly different from those of the Abbott, although they tend to be more argillaceous and micaceous. Both channel and sheet facies of sandstones are present. Limestones are thin but have appreciable lateral extent. They make up only a small amount (1 to 2%) of the formation.

Coals of the Spoon Formation are the earliest widespread coals of Pennsylvanian age in southern Illinois. Coals of economic importance are listed below.

- New Burnside Coal Member. This coal is well developed, but outcrops are scattered. It attains thicknesses up to 5 feet.
- Murphysboro Coal Member. Occurring in Jackson and western Williamson counties, this coal locally attains a thickness of 7 feet and is presently being mined close to the Jackson-Williamson county line. It is not uniformly well developed over the area of its occurrence.

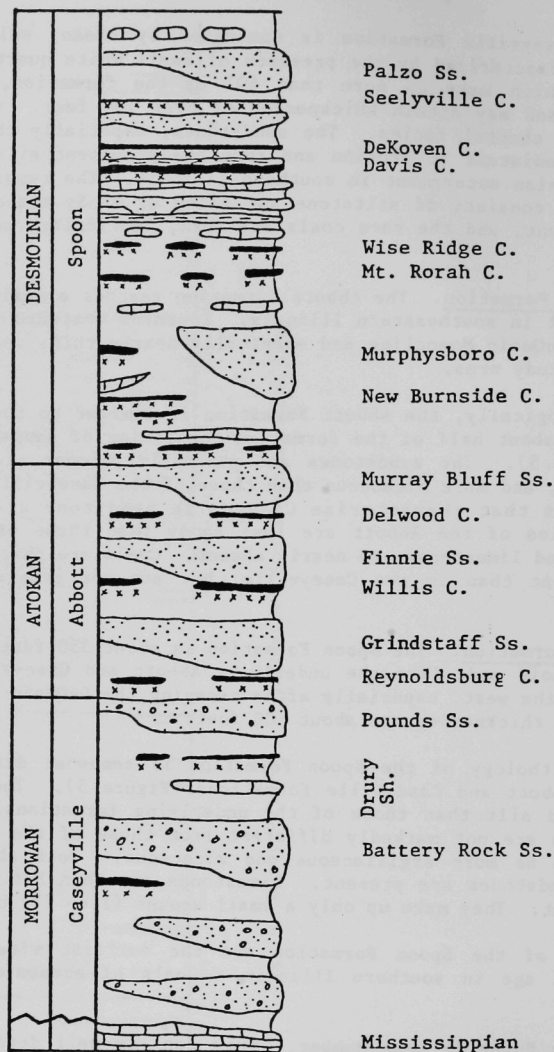


Fig. 5 Generalized Stratigraphic Column of Caseyville, Abbott, and Spoon Formations (after Hopkins and Simon, 1975)

- DeLong Coal Member. Seldom over 2 feet thick, this coal occurs sporadically throughout southern Illinois.
- Wise Ridge Coal Member. This is a thin, lenticular coal widely distributed across southern Illinois. It is too thin to be of economic importance.
- Davis Coal Member. The Davis is an important commercial coal in southern Illinois. It averages about 4 feet thick in much of the eastern part of southern Illinois where it has been extensively mined.
- DeKoven Coal Member. This coal occurs from a few feet to 40 feet above the Davis coal, and the two are commonly mined together. The DeKoven coal averages 3 feet in thickness. It occurs mainly in southeastern Illinois.

The stratigraphic interval between the Davis and DeKoven coals merits special mention. This zone frequently contains a black shale that is very pyritic. Where the pyritic shale is exposed to weathering, it produces some of the worst acid mine drainage problems in southern Illinois.

The combined thickness of the Caseyville, Abbott, and Spoon formations reflects and amplifies the westward thinning trend discussed under each individual formation. This portion of the Pennsylvanian has a maximum thickness exceeding 1200 feet in eastern Williamson and Western Saline counties, thins westward to slightly over 200 feet in northwestern Perry County, and becomes even thinner northwest from there. The greatest change in thickness occurs in the vicinity of the DuQuoin Monocline.

Carbondale Formation. The Carbondale Formation is presently defined as the interval from the base of the Colchester (No. 2) Coal Member to the top of the Danville (No. 7) Coal Member (Figure 6). The thickness of the Carbondale Formation follows the same general trend as the other Pennsylvanian formations. At the inner edge of its outcrop area in Saline County, it reaches over 400 feet in thickness and thins gradually both eastward and westward. Across the DuQuoin Monocline it thins rapidly to about 225 feet and continues the thinning trend westward until it reaches a thickness of about 175 feet along the Perry County-Randolph county border.

The Carbondale Formation consists mainly of gray shale and gray silty shale, which make up about 65% of the formation. Sandstones are locally prominent and, when in channel form, may reach thicknesses of 100 feet. Sheet-form sandstones are much thinner. The sandstones of the Carbondale Formation are commonly subgraywackes and tend to be more argillaceous than the older Pennsylvanian sandstones. Sandstones make up about 25% of the formation.

Limestones are fairly common, widespread and persistent. A typical limestone is gray to dark gray argillaceous and contains marine fossils. The typical thickness of the limestones is 1 to 5 feet, but they occur frequently enough to make up about 5% of the formation.

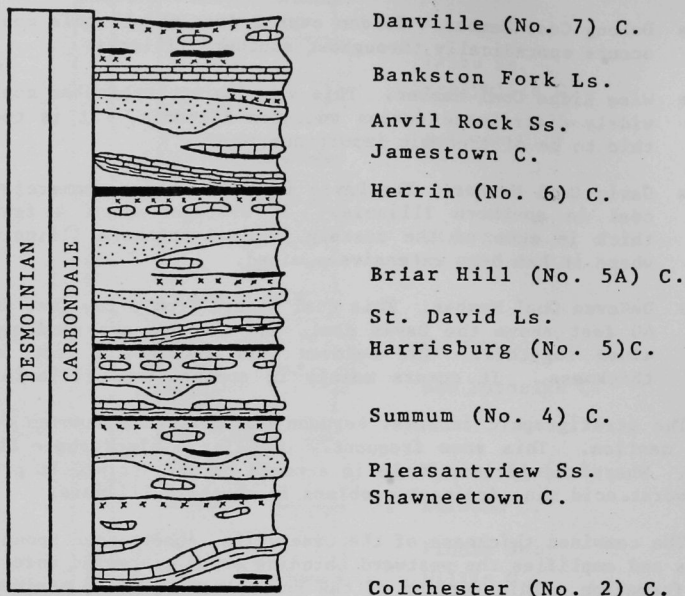


Fig. 6 Generalized Stratigraphic Column of the Carbondale Formation (after Hopkins and Simon, 1975)

Coals make up roughly 5% of the Carbondale Formation. They are abundant, widespread and persistent. Many are relatively thick, commonly ranging from 2 to 7 feet and occasionally reaching 15 feet in thickness. Below is a list of the coals of the formation, in ascending stratigraphic order, beginning with the Colchester (No. 2) Coal Member at the base of the formation.

- Colchester (No. 2) Coal Member. This is a very persistent coal that locally reaches a maximum thickness of 18 inches in southern Illinois. Although it does not appear to reach minable thickness in the area, its persistence makes it useful as a stratigraphic indicator horizon.
- Shawneetown Coal Member. This was formerly called the No. 2A Coal in southeastern Illinois. It is normally quite thin but in a few scattered drill holes has been reported to reach 8 feet. Where found, it is generally about 50 feet above the No. 2 and tends to be absent in the western part of the area.
- Summum (No. 4) Coal Member. This is another widespread, persistent coal used as a stratigraphic marker. Generally thin, the coal is reported to reach a maximum thickness of 2 to 3 feet in scattered drill holes in Randolph, Perry, and Jackson counties. It has been mined in a few

places in southeastern Williamson County and in Saline County and was being mined in two small pits in that area at the time of this study. It is associated with a black fissile shale horizon, 6 to 8 feet thick, that overlies the coal and makes the stratigraphic interval of the coal evident even when the coal is missing.

- Harrisburg (No. 5) Coal Member. This is the second most important coal commercially in Illinois. It overlies the No. 4 by an interval of 50 to 80 feet, with the lower end of this range more common in southwestern Illinois. Thickness of the coal reaches over 7 feet in Saline and Gallatin counties. It thins westward to less than 30 inches in most of the area west of the DuQuoin Monocline. One known exception to the low thickness west of the monocline is in the southwestern corner of Perry County and in an adjacent area in Randolph County, where the coal is from 5 to 7 feet thick. In part of southeastern Illinois, the coal is overlaid by a gray silty shale, the Dykersberg Shale Member. Where this shale occurs, the coal has lower sulfur content and more shale partings than where the more common black shale overlies the coal.
- Briar Hill (No. 5A) Coal Member. This is a thin discontinuous coal known in southeastern Illinois. It is of little commercial importance. It occurs in Gallatin and Saline counties within a zone of sandy strata. It reaches 18 to 30 inches in the Eagle Valley Syncline, but its thickness is very erratic.
- Herrin (No. 6) Coal Member. This is a bright-banded coal which ranks first in commercial importance in the state. The thickness pattern of the No. 6 coal is unlike that of most of the Pennsylvanian units in southern Illinois. The No. 6 coal tends to thicken going from eastern Gallatin County, where it tends to be less than 4 feet thick, toward western Williamson and northeastern Jackson counties, where it attains a thickness of 8 to 9 feet. However, in the middle of this zone of thick coal, there is a coal cutout caused by a sandstone channel located approximately along the border between Williamson County and Perry and Jackson counties. West of the cutout, the coal thins to the 5 to 7 feet.
- Jamestown Coal Member. This is a thin coal, seldom more than a few inches thick. Four to six inches is typical in the eastern counties.
- Danville (No. 7) Coal Member. This coal was formerly known in southwest Illinois as the Cutler Coal. It reaches a maximum thickness of about 18 inches in southwestern Illinois and a maximum of 30 inches in the southeastern counties.

The stratigraphic interval between the No. 5 and No. 6 coals is of importance because it occurs as spoil material in many strip mines in southern Illinois. The thickness of this sequence of rocks varies considerably, from about 125 feet in eastern Gallatin County to less than 25 feet in western Perry County. In general, the thicker, eastern portion of this interval is characterized by a higher percentage of sandstone than further west, and the shales are also thicker. Where the distances between the two coals is thin, limestones and clays predominate, and the clays and shales tend to be limey. In contrast to this, there is less than a foot of limestone present in much of the eastern area. This lack of neutralization potential, coupled with the presence of pyrite in the rocks above the No. 5 coal, allows the formation of acidic mine drainage water where the No. 5 coal has been surface mined in southeastern Illinois.

The Carbondale Formation rocks above the No. 6 coal present a different environmental situation. Although pyrite is present in some units, especially the Anna Shale Member, there are enough limestones in the section to neutralize acids generated by oxidative weathering. As a result, water draining from overburden that contains upper Carbondale Formation rocks commonly has high sulfate, hardness, and total dissolved solids, but usually has alkalinity exceeding acidity and neutral to above-neutral pH.

Modesto Formation. The Modesto Formation is the youngest Pennsylvanian formation found in most of the coal-producing area of southern Illinois. Thickness of the Modesto Formation is 225 feet in most of Perry County. East of the DuQuoin Monocline, thickness increases to over 375 feet in northeast Williamson County and thins again to a little over 300 feet thick in northernmost Saline and Gallatin counties.

The Modesto Formation is characterized by gray shale, but sandstones are locally prominent. The approximate distribution of lithologies is about 70% shale, 25% sandstone, 5% limestone, and less than 1% coal (Figure 7). It has thicker limestones and thinner coals than the underlying Carbondale Formation, and the presence of red shales also serves to distinguish it from the older formation. Coals in this formation are less than a foot thick and are not usually of commercial importance.

Only one member of this formation merits mention here. The Piasa Limestone Member (formerly called the Cutler Limestone) lies a few feet above the No. 7 coal. It is generally less than 4 feet thick in the southwestern part of the region but thickens to about 15 feet toward the east, where it is known as the West Franklin Limestone. This is a persistent limestone horizon which, because of its stratigraphic position in the lower part of the Modesto Formation, may occasionally be encountered in strip mine overburden in areas where the Carbondale Formation is thin (i.e., west of the DuQuoin Monocline).

Local Geology of Mine IL-2. The classical explanation of the middle Pennsylvanian sediments of the Carbondale formation has been that of cyclic deposition. Indeed, the sedimentary units of Mine IL-2 are parts of the Brereton, Jamestown, and Bankston cyclothems. However, more recent interpretations of these sediments suggest they are thin, interlayered, and intertonguing deposits of a broad, lobate delta advancing across a shallow marine

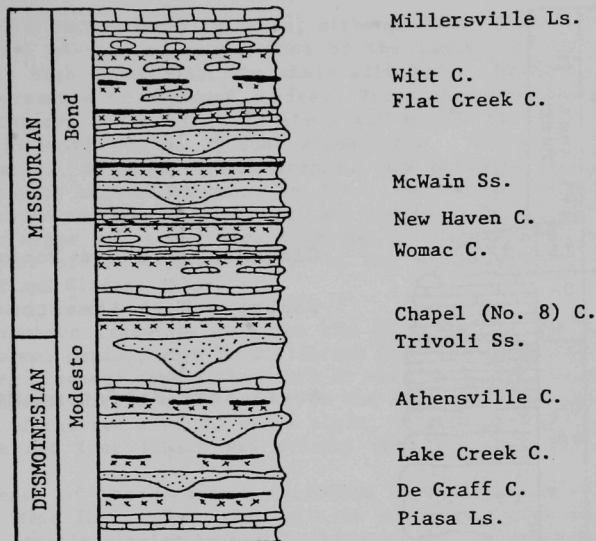


Fig. 7 Generalized Stratigraphic Column of the Modesto and Bond Formations (after Hopkins and Simon, 1975)

shelf, rather than classical cyclothems. The following interpretations, unless otherwise indicated, are mainly from Givins (1967) and Utgaard and Givins (1973). The accompanying diagram (Figure 8) from Givins (1967) shows the generalized stratigraphic sequence at Mine IL-2 as deduced from old exposures and mine workings over a several-year period.

The No. 6 coal is interpreted as forming in a series of widespread peat swamps on a low, broad delta plain. Eggert and Cohen (1973) have noted many similarities between fossils preserved in the coal balls that occur in this coal and the peat of the southeastern United States. Overlying the No. 6 coal in discontinuous patches is a gray shale, only sparsely present in the Mine IL-2 but thicker in other localized areas of southern Illinois where it may attain a thickness of 40 feet. Its origin is ambiguous because the presence of occasional cephalopods suggests marine conditions but its distribution and concave upward shape suggest an environment close to a detrital source. This may be a channel deposit or, in this writer's opinion, more likely a splay deposit. Although this shale is unimportant at Mine IL-2, it is of regional economic importance because in those places where it attains a thickness of several feet, the underlying coal has considerably less sulfur than usual.

Overlying the No. 6 coal, or the gray shale if it is present, is a black shale of sheety fissibility, the Anna Shale Member. Fossil assemblages at the very bottom suggest brackish water, but it contains marine fossils at higher levels (Grenda, 1969). Three things about this shale are striking:

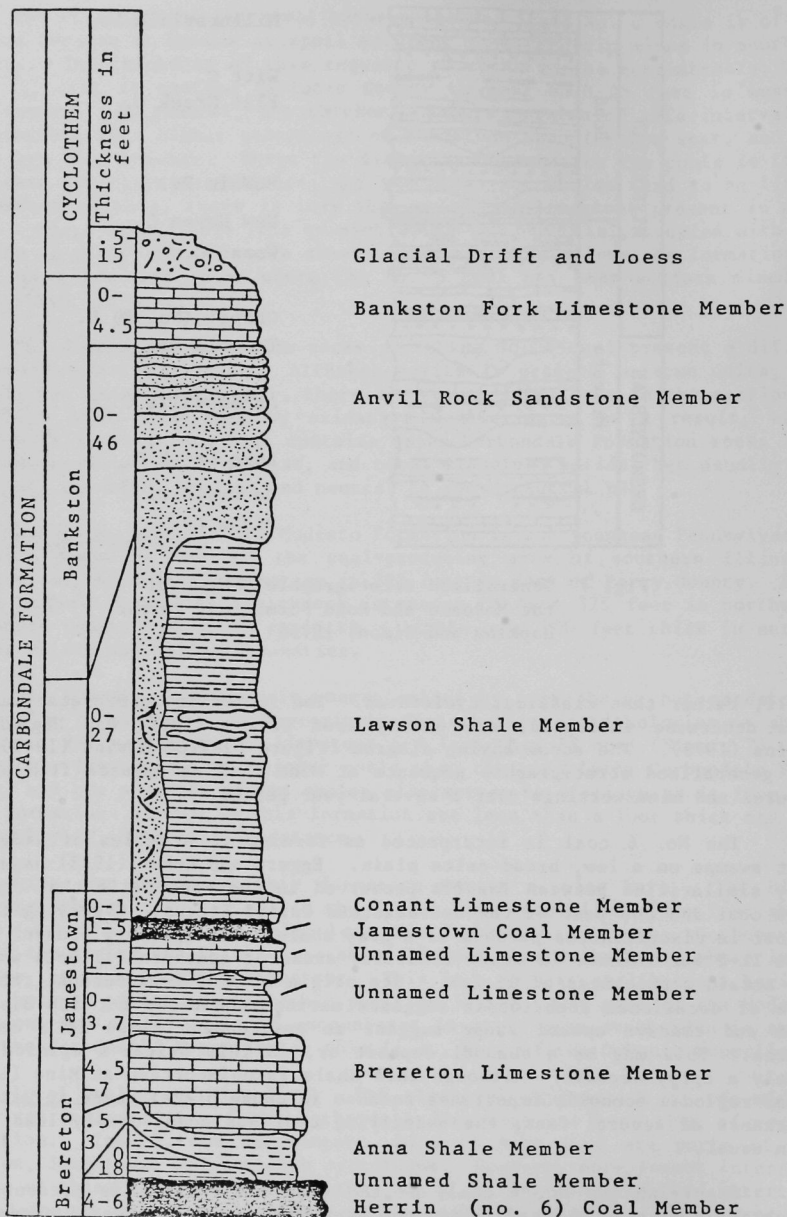


Fig. 8 Generalized Columnar Section Showing Cyclothem Members in the Study Area (from Givins, 1967)

the absence of a bottom-dwelling fauna, although other fauna are present; the almost complete absence of disturbance of the laminae of the shale; and a carbon content high enough that the shale will burn. Another important feature is the presence of abundant pyrite. These characteristics have led to the interpretation of the shale as the first marine transgression over the peat swamps in which the No. 6 coal accumulated. The water is thought to have been shallow, with the bottom stagnant and poisoned with hydrogen sulfide from decaying organic matter. The fine, undisturbed laminae suggest the bottom was protected from waves, tides, and storms, and it has been suggested that a thick algae mat could have provided such protection and could have been the source of the organic debris of the shale (Grenda, 1969; Givins, 1967; Utgaard and Givins, 1973).

The Brereton Limestone overlies the Anna shale. The Brereton Limestone is a normal marine, very fossiliferous limestone. In Mine IL-2, it becomes more argillaceous toward the south as well as upward, suggesting it may have interfingered with a shale source to the south. It may represent a further advance of the sea over the delta plain, or perhaps just a disappearance of the algae mat that likely was present when the Anna Shale originated.

Sediments of the Jamestown Cyclothem appear just above the Brereton Limestone in Mine IL-2. The first unit is an unnamed gray shale. It contains marine fossils similar to the Brereton at the top and bottom, but it is only sparsely fossiliferous in the middle, probably due to rapid accumulation of mud. It is interpreted as a prograding delta front.

Above the unnamed gray shale is marine limestone only a few inches thick. It is very similar to the Brereton Limestone, except that it contains fossil roots and served as a base upon which grew the plants that formed the next unit above, the Jamestown Coal. At Mine IL-2, this coal has a maximum thickness of two to six inches, with the more common thickness at the lower end of the range. Its presence on the limestone may indicate a slight shoaling of the water or perhaps a replacement of the marine water with fresh water. Above the Jamestown Coal, another thin limestone, the Conant Limestone Member, is present. It is very similar to the limestone below the coal.

Overall, the sequence from the unnamed gray shale just above the Brereton Limestone through the Conant Limestone makes up the Jamestown Cyclothem. This entire sequence is lacking in the northwestern part of southern Illinois. Overall, it appears to be a clastic wedge that entered southern Illinois from the east and interfingered with marine carbonates in the Mine IL-2 area. In other places in southern Illinois, the Lawson Shale Member, the next unit above the Conant Limestone at the mine, lies directly on the Brereton Limestone.

At Mine IL-2, the Lawson Shale lies on the Jamestown Cyclothem sequence. This shale is a medium gray, silty, carbonaceous shale. Some zones in the Lawson are extremely burrowed and some trails and grazing traces are present in the upper portion. Other types of fossils are absent. Wetendorf (1967) suggest that the Lawson Shale Member is a prodelta deposit or a delta front deposit on a lobate delta. Utgaard and Givins (1973) suggest an inter-distributary bay deposit as an alternative interpretation.

The Anvil Rock Sandstone Member is a light gray, very fine to medium-grained, micaceous, argillaceous sandstone. Both sheet and channel phases are present in various parts of the mine. The upper, thin-bedded parts of the channel phases are continuous laterally with the sheet phases. Wetendorf (1967) interprets the Lawson Shale and Anvil Rock Sandstone as being at least partly time equivalent. These two units together are interpreted as being the constructional phase of a low, broad delta that built out into the sea.

The Bankston Fork Limestone, an argillaceous, fossiliferous marine limestone, is only locally present in Mine IL-2.

The surficial materials at the mine include glacial till, some scattered sandy glacial outwash, and loess, all of quite variable thickness.

2.4 SOILS

The Ava-Bluford soil association dominates the area near Mine IL-2. This is a group of light-colored upland soils that developed under forest vegetation from parent materials consisting of less than 65 inches of loess overlying glacial till. Ava silt loam is the well-drained and most common member of the group that includes the very poorly drained Loy, poorly drained Wynoose, and the imperfectly drained Bluford silt loams. The area of active mining is almost entirely in areas of Ava and Bluford soils. Of these two soils, Bluford tends to develop on area slopes of 1 to 4%, whereas the Ava silt loam develops on slopes of 2 to 18%. All the soils in this association are acidic, with Wynoose having pH values from 4.0 to 4.4, Bluford a pH about 4.5, and Ava pH values varying from 4.4 to 4.6. Ava soils are poor in nutrients and have fragipans that retard deep root penetration. Bluford soils are also nutrient-poor, but do not have the well-developed fragipan.

The Grantsburg-Robbs Manitou silt loam association is a group of soils that has developed where loess cover overlies sandstone. The till associated with the Ava group is lacking in this association. Grantsburg is a light-colored silt loam that has developed under forest cover on slopes from 2 to 12%. Robbs is similar but develops on slopes between 1 and 4%. Manitou is the well-drained member, developing on slopes from 10 to 30%. All three of these soils are acidic, with Grantsburg ranging from 4.2 to 4.6, Robbs from 4.8 to 5.2, and Manitou from 4.8 to 5.0, although the A₁ horizon of Manitou soils can reach 6.0 (Fehrenbacher and Odell, 1959). Although this association is not present in the area of active mining, it was present in some previously mined areas and is present in some areas destined to be mined in the future.

2.5 HYDROLOGY

Surface Water. The study mine is located at the headwaters of a small stream in the Saline River drainage basin. Little information is available for this stream. A regional water-quality monitoring program conducted by the Greater Egypt Regional Planning and Development Commission included a station on this stream several miles downstream from the mine. During the

period of May to December 1976, flows ranging from 0 to 32 cfs were measured at the station, with flows in spring typically about 5 cfs (Hood, 1977).

The Illinois EPA has a monitoring station on the stream just above its confluence with a tributary of the Saline River (Illinois EPA, 1975). This location is also several miles downstream from the mine and contains discharge not only from Mine IL-2 but that of several other surface and underground mines in the area. In general, the water meets Illinois general water quality standards except for iron, manganese, sulfate, and total dissolved solids. In this respect it is very similar to many other streams in southern Illinois.

Groundwater. Only a small amount of water seeps from the highwall into the pit. In general, the only time that water in the pit becomes a problem is during periods of heavy rains. Groundwater does seep from the older spoil material into the receiving stream. However, it was not possible during this study to assess either the quality or the quantity of such seepage.

There are no significant aquifers in the area that may be directly affected by the mining operations. The Anvil Rock Sandstone occurs in the overburden but is not an important aquifer. Below the level of mining, some sandstone occurs in the interval between the No. 5 and No. 6 coals, but is separated from the mine water by several feet of underclay and shale, both of which have very low permeabilities. Davis (1973) has examined the quality of groundwater to a depth of 250 feet throughout much of southern Illinois. In the mine area, the shallow groundwater typically contains moderate chloride (40-160 ppm), high hardness (375 ppm and up), high sulfate (400-800 ppm), and high iron (frequently exceeding 150 ppm). Such water is not potable. These qualities are part of larger regional trends and have nothing to do with coal mining in the area.

Throughout southern Illinois, there are few areas of potable groundwater in appreciable quantity. For this reason, nearly all municipalities in the area are forced to depend on surface water.

3 SITE CHARACTERISTICS, SAMPLING, AND ANALYSES

3.1 MINE OPERATION

Production History. The mine operated under different company ownership in 1935, and production has continued each year since that time. Annual production has declined from about 1 million tons in 1971 to about 750,000 tons in the mid-1970s.

Expansion of the mine is planned, with the area of production extending into another county. This should increase the life of the mine by at least 20 more years.

Mining and Reclamation. Mining is done by the area method. Overburden is stripped from the coal by a 60-cubic yard Bucyrus-Erie dragline. An 11-cubic yard Marion shovel is used to load the coal, with some of the loading being done by front-end loader. Six haulage trucks were in use at the time of the study. Reclamation is being done in accordance with Illinois law, which requires that:

- Land, with certain exceptions, be returned to no more than a 15% slope.
- At least the upper eight inches of topsoil shall be replaced.
- Materials beneath the darkened surface soil to a depth of 4 feet contain no more than 20% coarse material greater than 2 mm. No more than half of the coarse material may be between 3 and 10 inches in diameter, and no fragments may exceed 10 inches in largest dimension. No more than 40% of the material may be clay.

To accomplish the reclamation work, two bulldozers are operated on a three shift per day basis, and two pan scrapers operate two shifts per day moving topsoil. A Northwest 3.5-cubic yard dragline is also used in reclamation as needed.

Revegetation at this mine begins with seeding in late February or early March with a minimum of 20 pounds of seed per acre. The seed mixture consists of about 50% fescue, 10% alsike, and 20% each of alfalfa and lespedeza. Where physically and economically feasible, a similar seeding is made in the fall on lands that were graded during the spring and summer months. Where autumn seeding is done, a further seeding with legumes is made during the following spring. Fertilizers are added as indicated by soil tests.

Effluent. No treatment of the mine effluent is being done. Settling ponds to remove suspended solids have not been constructed; however, the path of the drainage takes it through lakes that occupy old final cuts and haulage roads. The rate of water movement through these lakes is very slow, allowing lengthy residence time for suspended solids to settle out.

The intake water for the coal washing plant is in a different drainage basin from the area of active mining, and the water is of lower quality. The water is in a large old final cut and is nearly a closed system, with very little draining from the property. At one time, water from a large area of gob was diverted into the washing plant water system, lowering the pH considerably and markedly raising the iron concentration. This necessitated treatment, which was accomplished by introducing anhydrous ammonia into the system. Use of this material was discontinued months prior to the initiation of this study, and it is doubtful that any vestige of the treatment still exists in the system.

The water flow relationships are shown diagrammatically in Figure 9, which is a schematic diagram of water movement in the mine area.

Water Sampling. Water sampling stations were selected to represent water prior to passing the area of active mining, within the mined area, and essentially at the edge of the mined area. In and adjacent to this mine, it was possible to examine water that has been unaffected by any mining activity, water affected by past mining activities, and water affected by modern mining activities. Although Illinois has had a succession of reclamation laws which may have affected water quality, it was not possible to isolate waters associated with each stage in the evolving reclamation law at this mine. The station numbers and sample station descriptions are listed below and shown on Figure 10.

- 101 Upper reach of the receiving stream before it reaches the area of active mining. The drainage basin of the stream at this point contains a large percentage of land that was strip-mined in the 1950s.
- 102 The receiving stream, after water has entered from the present area of mining as well as areas mined during the mid-1970s.
- 103 The receiving stream, just prior to entrance of a small tributary that flows through a small lake occupying an old final cut. This lake is bordered on one side by spoil created by mining during the mid-1960s.
- 104 The receiving stream, after being joined by the small tributary. This is close to the point where the receiving stream leaves the mined area.
- 105 The small tributary, prior to any influence by mining.
- 106 The small tributary, after traversing mined land and an old final cut lake, but before entrance into the receiving stream.
- 107 Discharge from coal cleaning plant. The water flows from this point to the lake containing Station 108.

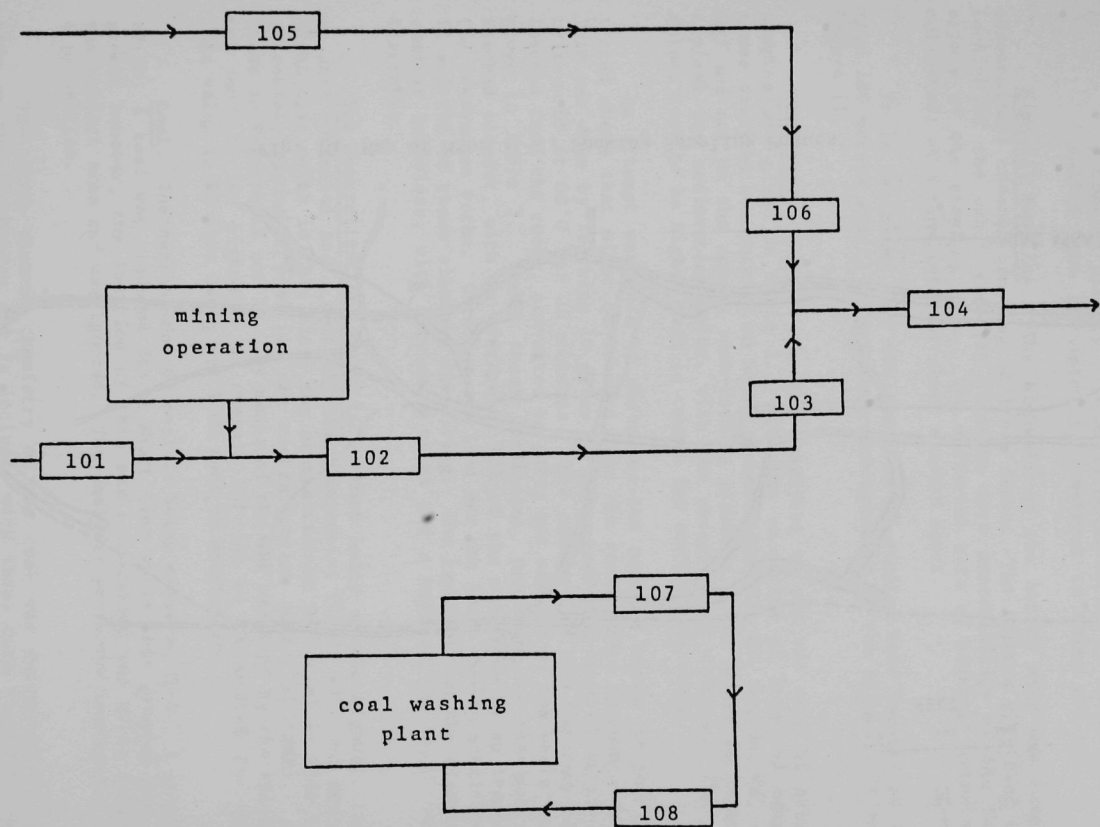


Fig. 9 Generalized Flow Diagram, Mine IL-2

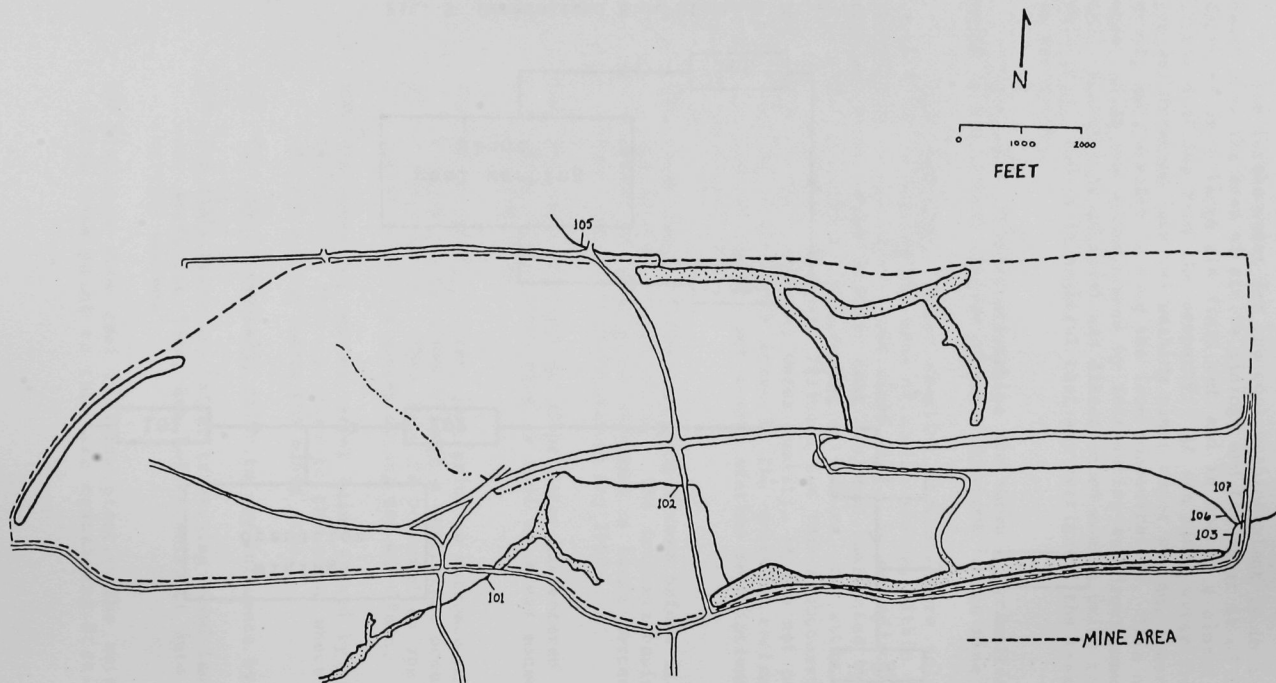


Fig. 10 Map of Mine IL-2, Showing Sampling Points

- 108 Intake water for the coal cleaning plant. This water is in a different drainage basin and different coal from the present mine area. Water in this lake has had a complex history of quality modification by diverting runoff from gob into it, treatment to raise pH, etc.

Highwall Sampling. The highwall of the active mine was sampled by conventional channel sampling on fresh faces. The factors governing the selection of the exact sampling location were accessibility of the face and safety of the sampling crew. Two different sets of highwall material were collected, at a time interval about a month apart.

It is estimated that the two sets of samples were located no further than 100 meters apart. A graphic representation of the highwall is shown in Figure 11.

Chemistry. Partial chemical analyses of the two sets of overburden samples are given in Table 2. With the exception of iron and manganese, these analyses concentrate on heavy elements (Zn, Ni, Cr, Co, Cu, Cd, Pb, and Hg) and not on the common rock-forming elements. The values in general are typical for sedimentary rocks, with the exception of cadmium. The cadmium values tend to be higher than is common for sedimentary rocks.

An attempt was made to determine the maximum amount of the elements listed above that might be leached from the rocks under optimum conditions. This was done by leaching 10 grams of pulverized rock with 20 mL of 1+1 nitric acid at 60°C for 20 minutes. The amounts of the various elements leached from the rocks, converted to parts per million of the whole rock, are given in Table 3. Under these conditions, manganese is the most easily leached element, with an average of 82% of the manganese being leached from the overburden rocks. Chromium and lead are the least easily mobilized, with 11 and 14% of these elements dissolving. The remainder of the elements show similar behaviors, with between a third and a half of the total being extractable.

Net Neutralizations Potential. Most units of the highwall have both an acid potential and a neutralization potential (Table 4). For most of the lithologic units in this mine, the neutralization potential exceeds the acid potential, giving a positive net neutralization potential (NNP). This is shown in Figures 12 and 13. By means of the NNP weighted by the thickness of the unit in the highwall, an overall NNP can be calculated for the mine. This value is 85 tons CaCO_3 per 1000 tons of overburden.

Coal. The Herrin (No. 6) coal is being mined at IL-2. A small amount of No. 4 coal was produced for a short time while this program was in progress; however, the location of this small operation was quite distant from the project area and was ignored. The analysis presented represents only No. 6 production.

The minor element chemistry of the coal was determined at the same time as the overburden and is included with those data (Table 2, Samples 1 and 1D).

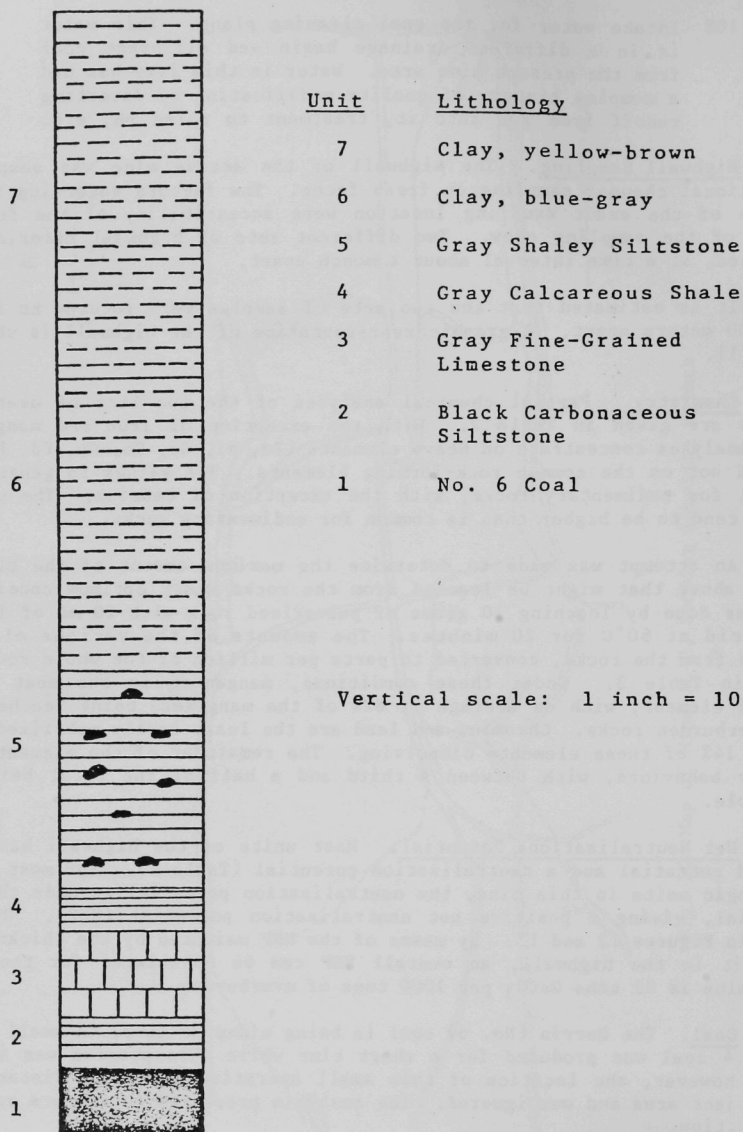


Fig. 11 Mine IL-2 Highwall

Table 2 Total Heavy Metals in Highwall Samples

Sample No.	Fe	Mn	Zn	Cd	Co	Cr	Cu	Pb	Ni	Hg
1	19,630	94	52.0	3.0	12.5	20.0	18.0	16.0	25.0	0.072
2	48,310	146	1176	78.0	104	1022	170	34.0	468	0.031
3	718	984	51.9	14.0	25.0	35.9	24.0	116	61.9	0.020
4	57,990	682	87.8	18.0	24.9	99.8	33.9	106	79.8	0.778
5	48,160	605	153	6.0	33.2	77.6	33.8	263	67.6	2.212
6	32,510	566	132	4.0	37.5	61.8	23.9	132	39.8	0.841
7	29,050	537	106	2.0	24.9	59.7	21.9	35.8	49.8	0.172
1D	10,100	56.0	36.0	18.0	62.7	37.2	12.0	38.0	30.0	0.008
2D	31,560	160	503	24.0	70.9	405	124	150	272	0.129
3D	11,530	788	28.0	22.0	104	20.6	16.0	14.0	74.0	0.109
4D	54,300	1283	38.0	18.0	70.7	58.8	26.0	20.0	136	0.200
5D	48,960	590	128	16.0	91.6	76.4	34.0	1580	62.0	0.112
6D	25,020	542	87.9	12.0	62.5	55.9	20.0	735	55.9	0.034
7D	35,470	781	79.9	18.0	37.6	52.0	20.0	318	79.9	0.053

Table 3 Acid-Leachable Heavy Metals in Highwall Samples

Sample No.	Fe	Mn	Zn	Cd	Co	Cr	Cu	Pb	Ni	Hg
1	16,470	32.9	36.8	0.5	2.8	1.2	6.0	2.5	7.0	0.034
2	25,970	94.6	1150	50.5	13.5	80.0	136	7.8	280	0.033
3	10	546	2.2	1.4	12.9	4.7	4.1	3.1	11.2	0.004
4	31,750	588	39.5	6.1	19.2	5.7	21.8	3.1	41.4	0.049
5	29,500	586	97.1	5.7	14.7	9.1	23.1	4.4	29.1	0.046
6	13,980	533	38.7	6.2	12.3	7.0	12.7	6.7	16.1	0.109
7	5,660	455	21.1	6.8	6.6	4.4	7.1	3.6	14.3	0.109
1D	7,590	47.6	10.7	0.4	1.2	1.0	3.7	2.5	5.9	0.008
2D	15,330	100	495	7.2	15.3	45.3	102	13.9	173	0.020
3D	30	648	4.0	1.8	13.5	5.7	5.6	6.9	18.4	0.021
4D	40,860	1268	7.3	1.3	17.1	5.7	15.7	10.7	50.1	0.016
5D	148	521	90.7	0.6	16.5	12.9	20.2	6.4	30.3	0.024
6D	13,800	457	40.5	0.5	12.6	5.7	12.0	6.4	19.6	0.007
7D	9,860	695	33.2	0.1	13.5	5.9	8.8	6.1	16.1	0.005

Table 4 Forms of Sulfur and Acid-Base Balance for Overburden

Sample No.	Depth (ft)	Munsell Value and Chroma	Lithology	Sulfur Fraction (%)			Tons CaCO ₃ Equivalent/1000 Tons Material	
				Total Sulfur	Sulfate Sulfur	Sulfide Sulfur	Acid Potential	Neutralization Potential
7	20-0	10 YR 7/4	Clay	0.01	--	0.02	0.6	100.1
6	45-20	5 YR 7/2	Clay	0.06	0.01	0.05	1.5	37.8
5	60-45	5 YR 6/1	Siltstone, shaley	0.54	0.04	0.50	15.7	16.3
4	63-60	5 YR 4/1	Shale, calcareous	2.35	0.30	2.05	64.1	99.2
3	69-63	N 7	Limestone, fine-grained	0.22	0.03	0.19	6.0	548.4
2	72.5-69	N 2	Siltstone, carbonaceous	3.61	--	3.77	117.8	26.1
1	77-72.5	5 YR 2/1	Coal	3.71	0.10	3.61	112.8	9.4
7D	20-0	5 YR 7/2	Clay	0.02	0.01	0.01	0.4	59.7
6D	45-20	5 YR 6/1	Clay	0.11	0.02	0.09	2.8	37.5
5D	60-45	N 6	Siltstone, shaley	0.65	0.07	0.58	18.0	24.5
4D	63-60	N 5	Shale, calcareous	4.78	0.83	3.95	123.4	471.8
3D	69-63	N 3	Limestone, fine-grained	0.25	0.01	0.24	7.5	554.2
2D	72.5-69	N 5	Siltstone, carbonaceous	2.22	--	2.23	69.7	23.1
1D	77-72.5	N 1	Coal	2.82	0.04	2.78	86.9	16.1

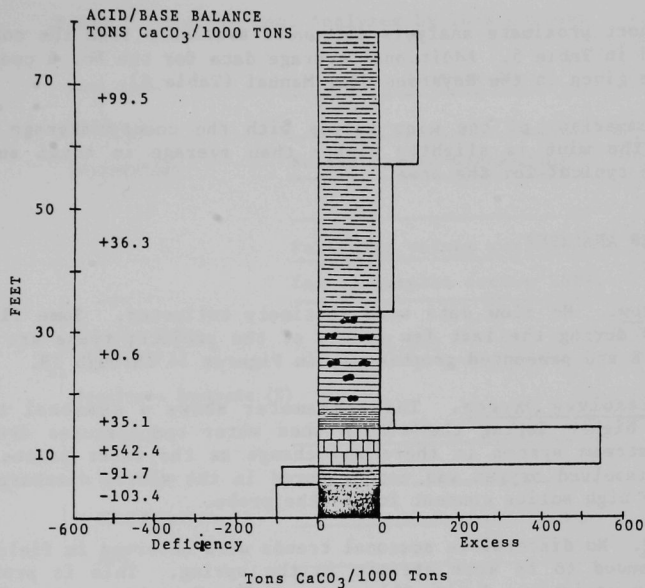


Fig. 12 Acid-Base Balance, First Sample Set

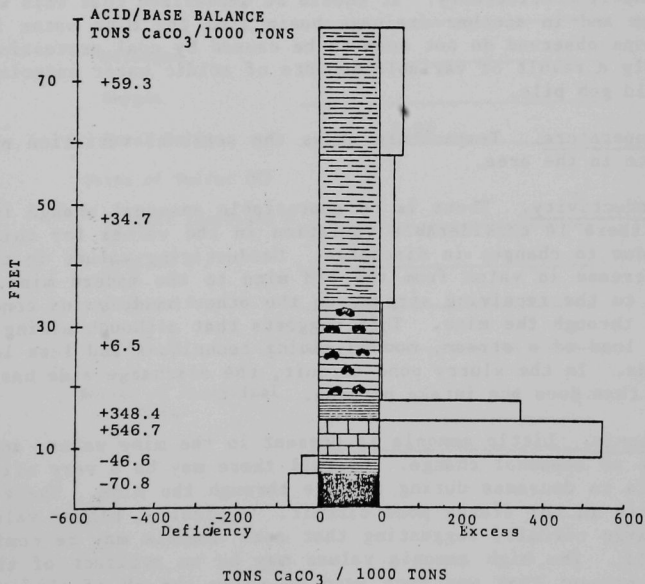


Fig. 13 Acid-Base Balance, Second Sample Set

Short proximate analysis data were available from the company and are presented in Table 5. Additional average data for the No. 6 coal in the mine areas are given in the Keystone Coal Manual (Table 6).

Comparison of the mine values with the county average suggests the coal at the mine is slightly higher than average in total sulfur, but is otherwise typical for the area.

3.2 WATER ANALYSES

Flow. No flow data were routinely collected. Some flow data were collected during the last few months of the project; these are tabulated in Appendix E and presented graphically in Figures 14 through 19.

Dissolved Oxygen. This parameter shows a seasonal trend, being slightly higher during the winter when water temperatures are lower. In neither stream system is there any change as the water passes through the mine. Dissolved oxygen was not measured in the slurry discharge stream because the high solids content fouled the probe.

pH. No discernible seasonal trends were observed in field pH, but the values tended to be more erratic in the spring. This is probably due to large flow variations during this season. No pH problem exists in the active mine, and water from the old mining area actually increases in pH as it passes through the modern mine. In the slurry pond circuit, pH is often low and fluctuates considerably. It should be emphasized that this water is isolated from and in another drainage basin from the mine water itself. The fluctuations observed do not seem to be caused by coal processing. They are more likely a result of variable amounts of acidic water entering the system from an old gob pile.

Temperature. Temperature shows the seasonal variation expected from the climate in the area.

Conductivity. There is no appreciable seasonal change in conductivity, but there is considerable variation in the values for this parameter, probably due to changes in discharge. Conductivity values in the receiving stream decrease in value from the old mine to the modern mine. The small tributary to the receiving stream, on the other hand, gains conductivity as it passes through the mine. This suggests that although mining adds to the dissolved load of a stream, modern mining techniques add less load than did old methods. In the slurry pond circuit, the discharge side has higher conductivity than does the intake portion.

Ammonia. Little ammonia is present in the mine water, and the parameter shows no seasonal change. Overall there may be a very slight tendency for ammonia to decrease during passage through the mine. There is appreciable ammonia in the slurry pond circuit. Typically, higher values occur in the discharge circuit, suggesting that some ammonia may be coming from the coal itself. The high ammonia values may be an artifact of the anhydrous ammonia treatment that was once used to raise the pH of the water in this system.

Table 5 Average Coal Analyses by IL-2 Company

Coal Name	Herrin (Number 6)
Thickness	
Description	Bright banded bituminous
	Following values average
	for 21 samples during 1977.
Heating Value (Btu/lb)	11,593
Proximate Analysis (%)	
Moisture	8.23
Volatile	
Fixed Carbon	
Ash	11.78
Ultimate Analysis (%)	
Hydrogen	
Carbon	
Nitrogen	
Oxygen	
Total Sulfur	2.96
Forms of Sulfur (%)	
Pyritic (sulfide) S	
Sulfate S	
Organic S	
Total S	
Source of Analytical Data	

Table 6 Coal Data for IL-2 Area

Coal Name	<u>Herrin (Number 6)</u>
Thickness	<u></u>
Description	<u>Bright banded bituminous coal</u>
	<u></u>
	<u></u>
Heating Value (Btu/lb)	<u>13,670 - 11,070, ave. 13,220</u>
Proximate Analysis (%)	
Moisture	<u>13.8 - 2.1, ave. 8.0</u>
Volatile	<u>40.4 - 29.6, ave. 35.3</u>
Fixed Carbon	<u>59.3 - 46.7, ave. 54.0</u>
Ash	<u>18.0 - 6.8, ave 10.5</u>
Ultimate Analysis (%)	
Hydrogen	<u></u>
Carbon	<u></u>
Nitrogen	<u></u>
Oxygen	<u></u>
Total Sulfur	<u></u>
Forms of Sulfur (%)	
Pyritic (sulfide) S	<u></u>
Sulfate S	<u></u>
Organic S	<u></u>
Total S	<u>4.2 - 0.5, ave. 1.5</u>
Source of Analytical Data	<u>Keystone Coal Manual</u> <u>1975, p. 68</u>

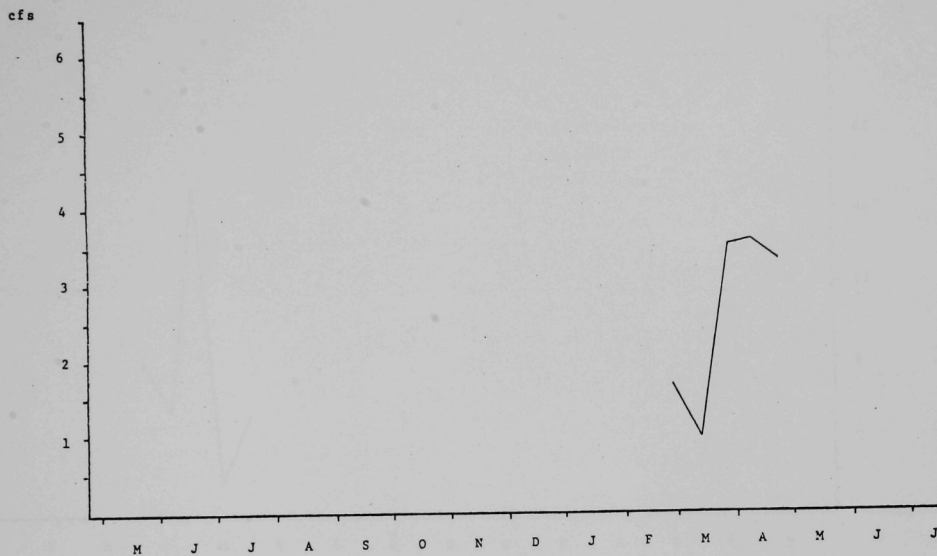


Fig. 14 Flow, Station 101

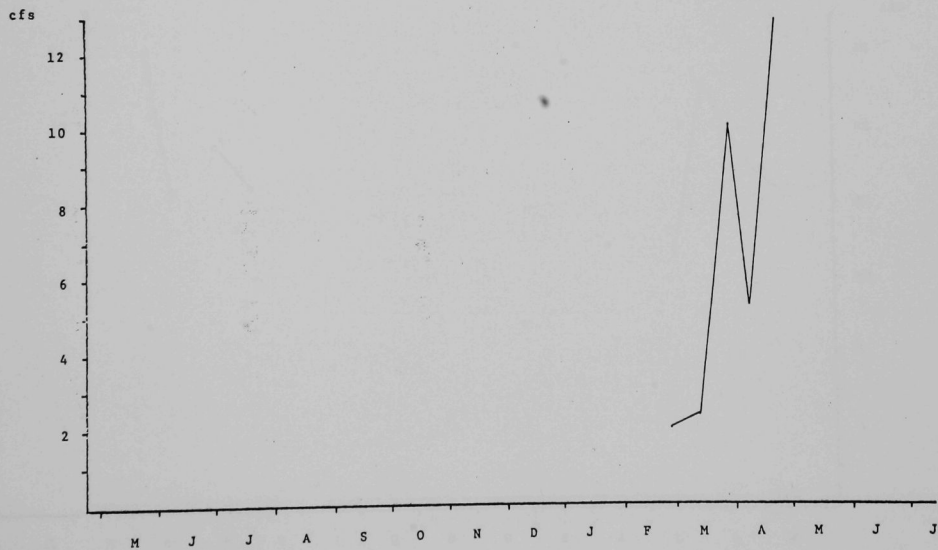


Fig. 15 Flow, Station 102

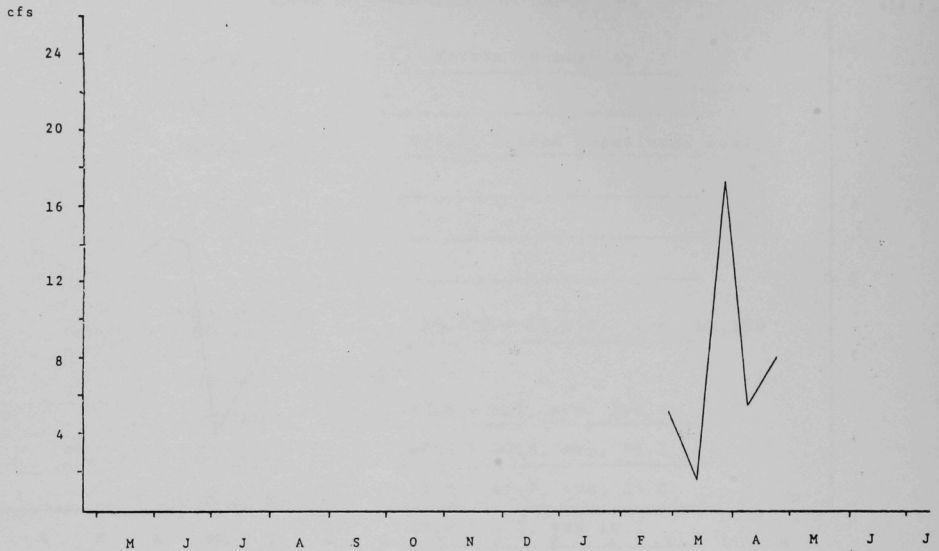


Fig. 16 Flow, Station 103

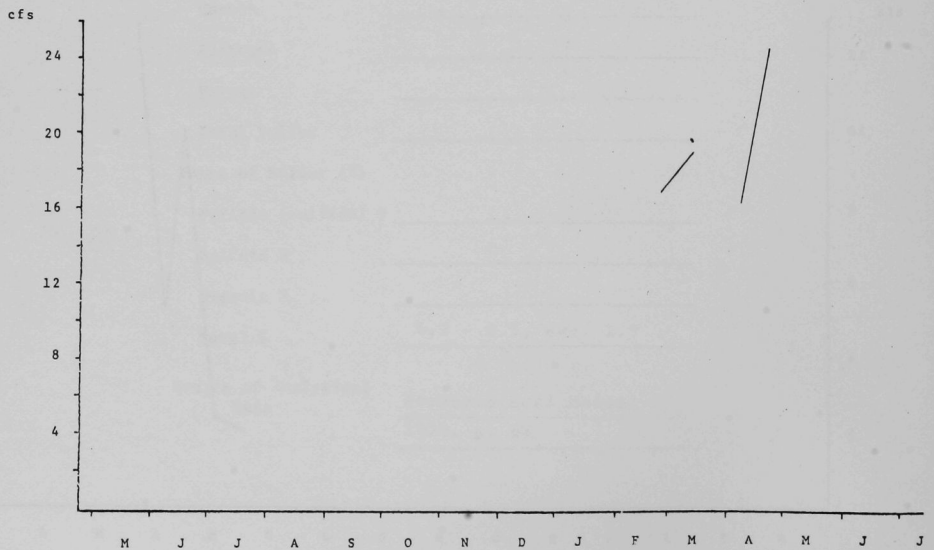


Fig. 17 Flow, Station 104

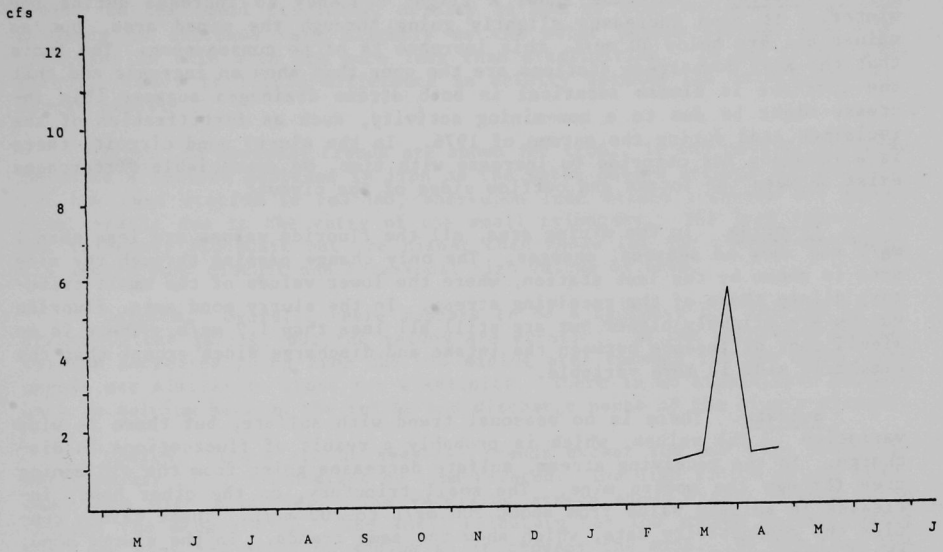


Fig. 18 Flow, Station 105

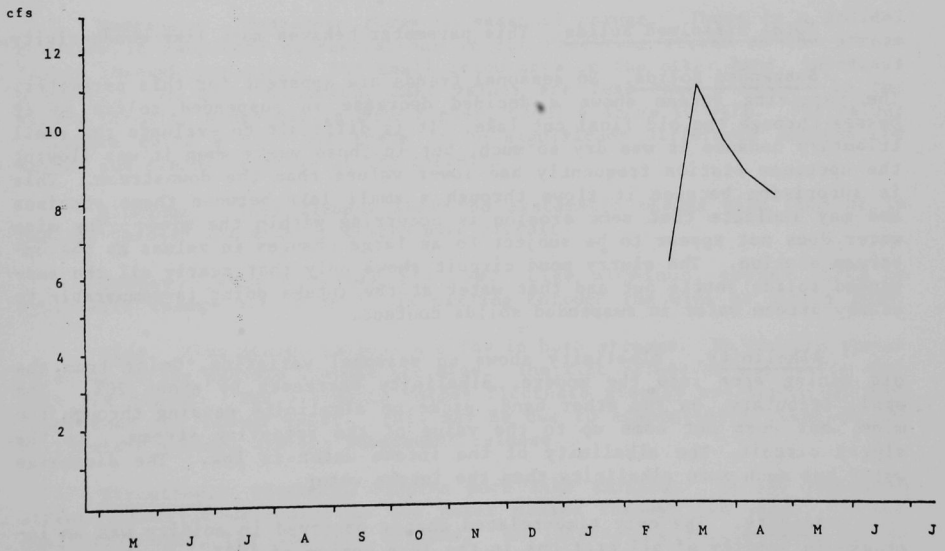


Fig. 19 Flow, Station 106

Chloride. Chloride shows a slight tendency to increase during the winter. It also increases slightly going through the mined area, but as values all are below 40 mg/L, this increase is of no consequence. The facts that the most downstream stations are the ones that show an increase and that the increase is almost identical in both stream drainages suggest this increase might be due to a non-mining activity, such as fertilization of the reclaimed land during the autumn of 1976. In the slurry pond circuit, there is a tendency for chloride to increase with time. No appreciable differences exist between the intake and outflow sides of the circuit.

Fluoride. In the mining area, all the fluoride values are less than 1 mg/L and show no seasonal changes. The only change passing through the mine area is shown by the last station, where the lower values of the small tributary dilute those of the receiving stream. In the slurry pond area, fluoride values are slightly higher but are still all less than 1.2 mg/L. There is no significant difference between the intake and discharge sides except that the discharge side is more variable.

Sulfate. There is no seasonal trend with sulfate, but there is wide variation in the values, which is probably a result of fluctuations in discharge. In the receiving stream, sulfate decreases going from the old mining area through the modern mine. The small tributary, on the other hand, increases in sulfate value from about 200 mg/L to 700 mg/L. These values confirm the conductivity data, which show the same trends. In the slurry pond, the discharge side has appreciably higher sulfate than the intake, suggesting that washing the coal adds sulfate to the water. However, the lack of build-up of this parameter in the water over the course of the study is surprising. Perhaps some sulfate mineral is precipitating from the water.

Total Dissolved Solids. This parameter behaves much like conductivity.

Suspended Solids. No seasonal trends are apparent for this parameter. The receiving stream shows a decided decrease in suspended solids as it passes through the old final cut lake. It is difficult to evaluate the small tributary because it was dry so much, but in those weeks when it was flowing the upstream station frequently had lower values than the downstream. This is surprising because it flows through a small lake between these stations and may indicate that some erosion is occurring within the mine. The mine water does not appear to be subject to as large changes in values as the upstream station. The slurry pond circuit shows only that nearly all the suspended solids settle out and that water at the intake point is comparable to nearby stream water in suspended solids content.

Alkalinity. Alkalinity shows no seasonal variation. Going from the old mining area into the modern, alkalinity decreases by about 20%. The small tributary, on the other hand, picks up alkalinity passing through the mine, but does not come up to the value of the receiving stream. In the slurry circuit, the alkalinity of the intake water is low. The discharge water has much more alkalinity than the intake water.

Acidity. The only time-related change observed in acidity was an increase in acidity of all stations in the late spring of 1977. In the receiving stream, acidity decreases as the water passes through the modern mining

area. In the small tributary, acidity is not as high and shows a general tendency to increase very slightly as the water passes through the mine. Acidities in this area are much less than alkalinities. In the slurry pond circuit, there is little difference in acidity between the intake and discharge sides.

Iron. No seasonal trends are shown for iron. In the receiving stream there is a decided decrease in iron as the water passes through the mine until the last station is reached, whereupon iron values increase and become more erratic due to the entry of the small tributary. The iron values for the tributary fluctuate but are higher than those for the receiving stream. The slurry pond circuit has occasional high values of iron.

Calcium. Overall, there appears to be a tendency for calcium to increase in the spring, but the values are erratic. In the receiving stream, calcium decreases going from the old mining area through the new mine. The trends are similar to those for alkalinity. There is no significant difference in calcium between the intake and discharge parts of the slurry circuit.

Sodium. There are no seasonal trends except for one high period in early summer 1977, which might be time-related. The high sodium values coincide with high acidities. The receiving stream shows little change going through the modern mine. The small tributary has low sodium values coming into the mine and picks up sodium as it crosses the mine. By the time the tributary enters the receiving stream, the two streams have about the same sodium content. In the slurry pond, the discharge water contains slightly more sodium than the intake water.

Manganese. Manganese shows no seasonal change. There is a decided decrease in manganese concentrations in the receiving stream as the stream passes through the mine. The small tributary, on the other hand, increases slightly. In both drainages, most values are less than 2 mg/L. In the slurry circuit, manganese is much higher, usually above 10 mg/L. The values fluctuate quite a bit, but there is no significant difference between the intake and discharge sides of the circuit.

Aluminum. This element shows no systematic change with time or in passage through the mine or slurry pond circuit.

Copper. Copper values are low. Like aluminum, copper shows no systematic change with time or in passing through the mine or slurry pond.

Zinc. Zinc concentrations are low in both streams. No changes appear to occur during passage through the mine. The zinc values of the slurry circuit are higher. The discharge values fluctuate greatly and are often much lower than the intake water. This may be due to adsorption of zinc on the particulate matter, and its subsequent release.

Strontium. Strontium behaves much like calcium. In the receiving stream strontium decreases as the water passes through the mine. In the small tributary, the opposite happens. An interesting relationship can be seen in the slurry circuit, where the discharge side has more strontium than the intake side. This probably indicates the cleaning operation releases strontium to the water but it tends to precipitate out of the water before reaching the intake point.

3.3 TREATMENT EFFECTIVENESS

Because no treatment is applied to these waters, treatment effectiveness obviously cannot be evaluated. However, the water leaving the mine has to meet environmental standards whether or not it has been treated, so some evaluation of its quality in reference to the suggested values should be made. The sampling was not designed to determine the extent of daily fluctuation or monthly average values. Inasmuch as the samples were taken at fixed time intervals over a lengthy period, this investigator feels they are representative enough to be used to judge both daily maximum and monthly average values for the various parameters.

pH. The pH of water leaving this mine can easily meet the standards of pH 6 to 9. Water in the slurry pond system, however, sometimes drops below this range.

Total Iron. Effluent from the mine can easily meet standards of 7 or 3.5 mg/L daily maximum and 3.5 or 3.0 mg/L 30-day average. Water in the slurry pond circuit, especially on the discharge side, occasionally exceeds both 7 and 3.5 mg/L daily maximum, but should meet the 3.5 and 3.0 mg/L 30-day average.

Manganese. Mine effluent can meet either a 4.0 mg/L daily maximum or a 2.0 mg/L 30-day average standard. The water in the slurry pond circuit, however, can meet neither of these. Manganese is widespread in southern Illinois waters and is related to pH and overburden characteristics. Water associated with overburden above No. 5 coal in southeastern Illinois is considerably higher than that associated with No. 6 coal. A comparison of the slurry pond water with the mine water shows this well.

Suspended Solids. At the sample location closest to where the mine water passes from the mine, only one sample exceeded 70 mg/L suspended solids during the sampling period. This means the settling ponds were about 95% effective in keeping the effluent below this level. Four samples exceeded 40 mg/L, meaning 86% of the samples were within the standard. Requiring a daily maximum value for suspended solids does not, to this investigator, appear to be a very realistic way to control effluent quality. This is because the suspended solids are very closely tied to amount, distribution, type, and intensity of precipitation, in addition to the kind and amount of ground cover, type of soil, etc. In the present case, in spite of very large settling ponds in the form of old final cuts, the daily maximum values of 40 and 70 mg/L were both exceeded. It seems probable to this investigator that even if a daily maximum value were higher, a storm of sufficient intensity and duration could add enough water to the drainage to cause flow through the ponds to be rapid enough to carry suspended material to the discharge point.

Five samples exceeded 35 mg/L, leaving 83% below this value for the sampling period. The arithmetic mean value for the discharge was 29 mg/L. Thus, it would take only a small increase in the suspended solid load to exceed the 35 mg/L standard. To evaluate a monthly average value from only two samples per month requires much extrapolation. If one assumes that each

value is representative of a two-week period, then it would take two successive samples with values greater than a given standard to produce a violation. In this mine, one episode of back-to-back samples exceeded 35 mg/L, suggesting that the mine would be in violation one month out of 15, or about 7% of the time.

For a standard of 20 mg/L, only 45% of the samples were less than this value, and back-to-back values in excess of this number occurred frequently. In about 7 months of the 15 the mine effluent exceeded 20 mg/L suspended solids. Thus, this mine could not meet a 20 mg/L standard using natural settling in spite of the very large settling ponds.

If this mine, using the large final cuts as settling ponds, cannot meet a 40 mg/L daily maximum 14% of the time and a 35 mg/L monthly maximum 7% of the time, it seems quite unlikely that a new mine being developed in the same area but without the benefits of old final cuts for settling ponds would be able to meet them either. Digging a pond of comparable size would be a large operation in itself and might cause as much environmental damage as it was designed to prevent. Many of the streams in the physiographic region of the mine appear historically to have had a high suspended solids load, as evidence by the names of some of them: Big Muddy River, Little Muddy, Mud Creek, etc. Perhaps a monthly value on the order of 45 to 50 mg/L would be more in keeping with the climate, geology, and soils of southeastern Illinois and still protect the streams against excessive environmental damage.

4 HEALTH AND ENVIRONMENTAL IMPACTS

4.1 IMPACTS ON SURFACE WATER

The mine has certain impacts on water quality when compared to water with no mining influence.

- Total dissolved solids are increased.
- Sulfate, which makes up one-half to two-thirds of the total dissolved solids, increases.
- Calcium (and therefore hardness) increases.
- Iron and manganese increase slightly.
- Suspended solids increase slightly.

When compared with water coming from the old mined area, most of these parameters actually improve. This indicates that the modern mining and reclamation techniques result in a better quality effluent than that from past activities. The differences are due to at least two factors. First, more attention is being given to preventing pyrite-bearing rocks from being left exposed on the surface; modern draglines give a considerable degree of control in the selective placement of overburden materials. Second, the surface is now graded so that more water runs off without having long periods of time in which to react with overburden rocks.

Overburden handling is probably the more important of these factors. Total dissolved solids, sulfate, calcium (and hardness), iron, and manganese are all interrelated. If rocks containing iron sulfide are allowed to oxidize, iron is mobilized and acid and sulfate are generated. Sulfate is the main component of total dissolved solids, so that also goes up as sulfate increases. The acid reacts with the overburden rock to release calcium, manganese, and other elements, giving as a net result an acidic, mineral-laden calcium sulfate water.

The key to stopping this is to prevent the iron sulfate from oxidizing, or at least to keep the oxidation rate as low as possible. This can be done best by immediately reburial of the strata that contain acid-producing minerals and by having carbonate-bearing rocks above them in the mine. This is being attempted in the modern part of Mine IL-2.

The effect of topsoiling, which has recently begun in Illinois, cannot be assessed at this time. What a law requiring replacement of topsoil does relative to the question of mine effluent quality is to ensure that there is a layer of weathered material, presumably free of acid-producing minerals, above any acid-producing rocks. It should have the effect of reducing the oxidation rates of any pyritic materials below it.

4.2 IMPACTS ON GROUNDWATER

In this mine, impact of mining on groundwater quality and quantity is minimal. There are no important aquifers in the mine area that could be polluted, and the overall quality of groundwater in southern Illinois is already poor.

The most important aspect of groundwater impact is the fact that the mine itself creates a groundwater reservoir. The spoil material has a high porosity and permeability and acts like a large "sponge" to absorb large quantities of rainfall. This stored water is then available as base-line discharge just like other groundwater. The author has observed hydrographs of streams with large areas of surface-mined land within their basins. Compared with those of nearby streams, the peak discharges and low flows are smoothed out. This should improve some aspects of survival of the stream biota.

APPENDIXES*

*The tables and graphs in Appendixes E and F are reproduced as received by Argonne from the author, with no enhancement of the camera-ready copy.

The first of these is the fact that the author has not only written a book which is both a work of art and a work of science, but has also written a book which is both a work of art and a work of science. The second is the fact that the author has not only written a book which is both a work of art and a work of science, but has also written a book which is both a work of art and a work of science.

The third is the fact that the author has not only written a book which is both a work of art and a work of science, but has also written a book which is both a work of art and a work of science. The fourth is the fact that the author has not only written a book which is both a work of art and a work of science, but has also written a book which is both a work of art and a work of science. The fifth is the fact that the author has not only written a book which is both a work of art and a work of science, but has also written a book which is both a work of art and a work of science.

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Appendix A

Analytical Procedure for Overburden

Digestion. The digestion procedure used was that of Shapiro and Brannock (1962), modified slightly to provide higher concentrations of material in solution.

- a. In a Teflon crucible, weigh approximately 0.50 grams of sample to the nearest 0.1 milligram.
- b. Under a fume hood, add 10 mL of acid mixture, and swirl to wet the sample.
- c. Place the crucible on a hotplate, and heat until SO_2 fumes start to evolve.
- d. Remove from heat, add 20 mL of distilled deionized water, and re-heat, swirling occasionally, until material dissolves.
- e. Transfer to 100-mL volumetric flask, and dilute to volume with distilled deionized water.
- f. Transfer to clean polyethylene bottle for storage.

Reagent. Acid mixture: 200 mL HF (48%), 66 mL H_2SO_4 (concentrated), and 16 mL HNO_3 (concentrated). Working under a fume hood, transfer the HF to a 1-L polyethylene bottle. Add the H_2SO_4 and allow to cool. Add the HNO_3 and mix.

Analyses. Analyses were made by standard atomic absorption techniques except for mercury, which was done by a flameless atomic absorption technique.

Working curves, except for mercury, were made at 1, 2, 5, and 10 mg/L with acid-spiked standard solutions. Unknowns were compared directly with the curves. Dilutions, where necessary, were made with distilled deionized water. For samples with values of less than 1 ppm, the signal was amplified until the 1-ppm standard registered 1000 on the instrument readout; the sample was then reanalyzed.

Mercury was analyzed with a 25-mL portion of the dissolved sample solution, run as if it were a water sample. Standard solutions in this case did not exceed 20 ppb, and samples were reanalyzed using smaller amounts of sample if the value exceeded this amount.

Estimated Detection Limits

Fe	1	ppm	Cr	1	ppm
Mn	1	ppm	Cu	1	ppm
Zn	1	ppm	Pb	1	ppm
Cd	0.2	ppm	Ni	1	ppm
Co	1	ppm	Hg	0.005	ppm

APPENDIX A

ANALYSIS OF THE DATA

The first step in the analysis of the data was to determine the distribution of the data. The data was found to be normally distributed.

The next step was to determine the mean and standard deviation of the data. The mean was found to be 1.5 and the standard deviation was found to be 0.5.

The third step was to determine the confidence interval for the mean. The confidence interval was found to be 1.0 to 2.0.

The fourth step was to determine the hypothesis test. The hypothesis test was found to be significant.

The fifth step was to determine the power of the test. The power of the test was found to be 0.8.

The sixth step was to determine the effect size. The effect size was found to be 0.5.

The seventh step was to determine the confidence interval for the standard deviation. The confidence interval was found to be 0.3 to 0.7.

The eighth step was to determine the hypothesis test for the standard deviation. The hypothesis test was found to be significant.

The ninth step was to determine the power of the test for the standard deviation. The power of the test was found to be 0.8.

The tenth step was to determine the effect size for the standard deviation. The effect size was found to be 0.5.

The eleventh step was to determine the confidence interval for the correlation coefficient. The confidence interval was found to be 0.3 to 0.7.

The twelfth step was to determine the hypothesis test for the correlation coefficient. The hypothesis test was found to be significant.

The thirteenth step was to determine the power of the test for the correlation coefficient. The power of the test was found to be 0.8.

The fourteenth step was to determine the effect size for the correlation coefficient. The effect size was found to be 0.5.

ANALYSIS OF THE DATA

1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8

Appendix B

Coal Analyses

A 1-g sample of coal was weighed to the nearest 0.1 mg in a porcelain crucible and covered with a loose-fitting lid. The covered crucible was placed in a furnace and heated slowly to 600°C to oxidize the organic fraction of the coal. The crucible was allowed to cool, after which the ash was transferred to a Teflon beaker. From this point, the sample was treated like overburden material.

Coal Analysis

A 1-g sample of coal was weighed to the nearest 0.1 mg in a tared container and covered with a few milliliters of water. The covered container was placed in a fume hood and heated slowly to 100°C to remove the moisture. The water was then allowed to boil away until the sample was completely dry. The sample was then cooled and weighed to the nearest 0.1 mg. The weight of the sample was then divided by the weight of the original sample to give the percentage of dry coal.

Appendix C

Water Collection and Handling

Bottles. One 1000-mL bottle and one 500-mL bottle were used for each station. Bottles were rinsed and acid soaked to remove any adsorbed ions or precipitates. Subsequently, they were washed with Alcanox and rinsed with tap water, then distilled water, and finally distilled deionized water. After air drying, they were capped until ready for field use.

Collection. Samples were collected as close to the midpoint of flow and mid-depth as practical. Two samples were taken at each site, one untreated and one acidified. The untreated sample was filled as full as possible and then tightly capped. The acidified sample was not completely filled to prevent loss of the acid. Care was taken not to disturb the bottom sediment at the point of sample collection.

Preservation. The only preservation used was 2 mL of concentrated HNO_3 in the 500-mL bottle to preserve metals.

Handling. The collection and analysis scheme was designed so that water samples were returned to the lab and analysis of critical parameters (pH, acidity, alkalinity, etc.) begun within four hours of collection (and often less).

Flow measurements. A cross section of each sample location was constructed at the time the first set of flow measurements were taken. In streams, flows were measured at mid-depth and mid-stream with a current meter which measured velocity in feet per second. Water depths were measured at mid-stream and used, in connection with the measured profile, to determine stream cross-section area.

Water Collection and Sampling

Procedure - Two 100-ml bottles and two 500-ml bottles were used for each station. The 100-ml bottles were used for water samples and the 500-ml bottles for sediment samples. The water samples were collected from the surface of the water, and the sediment samples were collected from the bottom of the water. The water samples were collected by pouring the water from the bottle into the 100-ml bottle, and the sediment samples were collected by pouring the sediment from the bottle into the 500-ml bottle.

Results - Samples were collected at three stations in the vicinity of the dam. The samples were collected at stations 1, 2, and 3. The results of the water samples are shown in Table 1, and the results of the sediment samples are shown in Table 2. The water samples were collected from the surface of the water, and the sediment samples were collected from the bottom of the water. The water samples were collected by pouring the water from the bottle into the 100-ml bottle, and the sediment samples were collected by pouring the sediment from the bottle into the 500-ml bottle.

Discussion - The only parameter measured was the pH of the water. The pH of the water was measured at each station, and the results are shown in Table 3. The pH of the water was measured by using a pH meter.

Conclusions - The pH of the water was measured at each station, and the results are shown in Table 3. The pH of the water was measured by using a pH meter. The pH of the water was found to be slightly acidic at all three stations.

References - 1. "The Effect of pH on the Solubility of Metals," *Journal of Environmental Science and Technology*, vol. 1, no. 1, pp. 1-10, 1967. 2. "The Effect of pH on the Solubility of Metals," *Journal of Environmental Science and Technology*, vol. 1, no. 1, pp. 1-10, 1967. 3. "The Effect of pH on the Solubility of Metals," *Journal of Environmental Science and Technology*, vol. 1, no. 1, pp. 1-10, 1967.

Appendix D

Analytical Procedures for Water

Procedures were carried out according to Standard Methods (1971), except those for ammonia and mercury, which used the EPA manual (U.S. Environmental Protection Agency (1979).

Filtration. Filtration was done in the laboratory with Reeves-Angel glass-fiber filter paper. Filtration was generally completed two to five hours after collection of the sample, after alkalinity and acidity titrations were completed for the sample.

Ammonia. Analysis was done with an Orion ammonia-sensitive electrode. Standards were prepared at 0.01, 0.1, 1, and 10 mg/L NH_3 .

Fluoride. Analysis was done with an Orion solid-state, fluoride-sensitive electrode. Each total ionic strength buffer was added to the sample and standards to adjust pH complex interfacing ions, and ionic strength.

Total Dissolved Solids. Analysis was done by evaporation of known volume (100 mL) of solution and drying of residue at 105°C.

Total Suspended Solids. Analysis was done by vacuum filtration of 250 mL of sample through Reeves-Angel glass fiber filter paper followed by drying at 105°C and weighing.

Alkalinity. Analysis was done by potentiometric titration, as soon as possible after opening the sample bottle.

Acidity. Analysis was done by potentiometric titration, as soon as possible after running alkalinity. The bottle was opened, the sample extracted and run for alkalinity; then the bottle was reopened and analyzed for acidity. Standard titrant was protected from atmospheric CO_2 by an Ascarite scrubber tube. Titration end point = 8.3.

Total Iron. Analysis was done by atomic absorption (AA) spectrophotometry on acidified sample. Analyses were done in triplicate, and the average value was used. Dilutions, when necessary, were with distilled deionized water.

Ca, Mn, Al, Cu, and Zn. These metals were determined by standard AA spectrophotometry on a Perkin-Elmer Model 107 AA spectrophotometer. Dilutions, when necessary, were with distilled deionized water.

Sodium and Strontium. These elements were determined with a Perkin-Elmer AA spectrophotometer operating in the flame-emission mode.

Cd, Co, Cr, Ni, and Pb. These elements were pre-concentrated before analysis by chelation with ammonium pyrrolidine dithiocarbamate and extraction into methyl isobutyl ketone. Standard solutions were similarly treated. A Perkin-Elmer Model 107 AA spectrophotometer was adjusted to provide for an organic solvent, and the metals were determined by AA spectrophotometry.

Mercury. This element was determined by flameless AA cold vapor technique with the Perkin-Elmer Mercury Analysis System.

ARGONNE NATIONAL LABORATORY
ECT Water Data

Parameter	Units	Filter Method Field/Lab	Sample Preser- vation	Analyt- ical Method	Method Refer- ence	Lower Detec. Limit
Effluent flow	gal./min.	---	---	current meter		
Diss. Oxygen	mg/l	---	---	D.O. meter	1, p.484	
pH (field)	--	---	---	---	---	---
pH (lab)	--	---	---	---	---	---
Temp. (water)	C°	---	---	---	---	---
Temp. (air)	C°	---	---	---	---	---
Specific Conductance	µmhos/cm at 25 C	---	---	conduct- ivity meter		
Ammonia-N	mg/l	G1. fiber filter lab	none	ion electrode	2, p.165	0.01 mg/l
Chloride	mg/l	"	"	titration	1, p.96	0.5 mg/l
Fluoride	mg/l	"	"	ion electrode	1, p.172	0.01 mg/l
Sulfate	mg/l	"	"		1, p.333	10 mg/l
TD Solids	mg/l	"	"	evap. at 105°C	1, p.290	1 mg/l
TS Solids	mg/l	"	"	filtra- tion	1, p.291	1 mg/l
Alkalinity	mg/l as CaCO ₃	unfiltered	"	titration	1, p.52	5 mg/l (CaCO ₃)
Acidity	mg/l as CaCO ₃	unfiltered	"	titration	1, p.50	2 mg/l (CaCO ₃)

- 1.) Standard Methods for Examination of Water and Wastewater, 13th ed.
- 2.) Manual of Methods for Chemical Analysis of Water and Wastes,
U.S. E.P.A., 1974.

ECT Water Data (Contd.)

Parameter	Units	Filter Method Field/Lab	Sample Preser- vation	Analyt- ical Method	Method Refer- ence	Lower Datec. Limit
Total Fe	mg/l	unfiltered	HNO ₃	Std. A.A.	1, p210	0.01 mg/l
Diss. Fe	mg/l	-----	---	----	---	---
" Ca	mg/l	unfiltered	HNO ₃	Std. A.A.	1, p210	0.01 mg/l
" Mg	mg/l	-----	---	----	----	----
" Na	mg/l	"	"	flame emission	1, p316	0.01 mg/l
" Mn	mg/l	"	"	Std. A.A.	1, p210	0.01 mg/l
" Al	mg/l	"	"	Std. A.A.	1, p210	0.1 mg/l
" Cu	mg/l	"	"	Std. A.A.	1, p210	0.01 mg/l
" Zn	mg/l	"	"	Std. A.A.	1, p210	0.01 mg/l
" Sr	mg/l	"	"	flame emission	1, p328	0.01 mg/l
" Hg	mg/l	"	"	flameless A.A.	2, p118	0.0001 mg/l
" Cd	mg/l	"	"	complex- ing Std. A.A.	1, p211	0.001 mg/l
" Co	mg/l	"	"	"	1, p211	0.01 mg/l
" Cr	mg/l	"	"	"	1, p211	0.01 mg/l
" V	mg/l	-----	-----	-----	---	-----
" Mo	mg/l	-----	-----	-----	-----	-----
" Ni	mg/l	unfiltered	HNO ₃	complex- ing Std. A.A.	1, p211	0.01 mg/l
" Pb	mg/l	"	"	"	1, p211	0.01 mg/l
" K	mg/l	-----	-----	-----	-----	-----

1.) Standard Methods for Examination of Water and Wastewater, 13th ed.

2.) Manual of Methods for Chemical Analysis of Water and Wastes,
U.S. E.P.A., 1974.

Appendix E
Water Quality Data

Mine Name (and/or code) _____ Date 6/8/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	*302	303	305	306	307
Flow, cfs						
Diss. O ₂	11.2	8.3	8.3	8.2		7.8
pH (field)	7.60	7.45	7.20	7.40	7.15	7.05
pH (lab)	7.61	7.64	7.01	7.23	6.64	6.98
Temp. (H ₂ O)	24	25	24	23	22	23
Temp. (air)						
Cond.	5070	477	6562	6860	6562	6761
Ammonia-N	1.43	1.54	1.83	1.79	8.32	4.90
Chloride	66	13	64	21	23	16
Fluoride	0.66	0.22	0.78	0.68	0.73	0.69
Sulfate	2286	85	3105	3096	3289	3165
TU Solids	4040	264	5362	6450	6245	6357
TS Solids	86	492	62	27	66,880	44
Alkalinity	695	141	720	525	587	526
Acidity	91	28	168	197	391	358
Total Fe	2.00	10.4	1.0	0.30	57.9	0.27
Diss. Fe						
" Ca	50.4	21.8	70	139	134	145
" Mg						
" Na	1229	27.7	1481	1463	1424	1372
" K						
" Mn	0.30	0.17	0.22	0.07	0.15	0.14
" Al	4.38	21.50	1.30	0.03	8.70	0.60
" Cu	0.02	0.35	0.02	0.04	0.25	0.00
" Zn	0.01	0.04	0.00	0.01	0.02	0.01
" Sr	1.79	0.11	2.60	8.5	1.99	9.10
" Cd	0.019	0.015	0.015	0.018	0.026	0.016
" Co	0.07	0.02	0.04	0.07	0.05	0.09
" Cr	0.00	0.00	0.00	0.00	0.01	0.00
" V						
" Pb						
" Ni	0.15	0.01	0.07	0.08	0.09	0.12
" Fe	0.04	0.00	0.03	0.00	0.06	0.03
" Hg	0.0001	0.0001	0.0002	0.0002	0.0000	0.0001

moved downstream after this date in order to sample additional drainage.

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 6/22/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites																			
	301	302	303	305	306	307*														
Flow, cfs																				
Diss. O ₂	13.2	8.5	5.4	8.0	8.4	8.0														
pH (field)	8.00	7.95	7.40	7.70	7.80	7.40														
pH (lab)	8.20	8.42	7.54	8.00	8.25	7.64														
Temp. (H ₂ O)	20	20	20	20	21	24														
Temp. (air)																				
Cond.	6304	4912	7196	6579	4245	4373														
Ammonia-N	4.17	2.85	7.08	3.49	4.72	3.26														
Chloride	93	84	98	20	13	13														
Fluoride	0.80	0.88	1.07	0.76	0.65	0.62														
Sulfate	3078	2060	3139	3132	2245	2278														
TD Solids	5238	3772	6229	6436	3590	3662														
TS Solids	135	76	45	28	52	39														
Alkalinity	731	603	880	527	326	340														
Acidity	6	0	50	19	8	30														
Total Fe	0.77	0.14	0.00	0.02	0.18	0.11														
Diss. Fe																				
" Ca	24.2	19.1	38.0	59.5	48.7	49.3														
" Mg																				
" Na	1727	1474	1813	1657	1195	1199														
" K																				
" Mn	0.00	0.04	0.34	0.00	0.05	0.09														
" Al	1.61	0.68	0.68	0.17	0.78	0.77														
" Cu	0.02	0.01	0.01	0.02	0.01	0.03														
" Zn	0.00	0.00	0.01	0.00	0.00	0.00														
" Sr	2.39	1.34	3.36	3.09	2.83	2.87														
" Cd																				
" Co																				
" Cr																				
" V																				
" Pb																				
" Ni																				
" Pb																				
" Hg																				

* No Flow

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 7/6/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs						
Diss. O ₂	12.7	8.4	7.8	7.7		8.9
pH (field)	8.05	7.95	7.45	7.65	7.60	7.55
pH (lab)	8.41	8.26	7.64	7.88	7.90	7.97
Temp. (H ₂ O)	23	24	25	25	27	26
Temp. (air)						
Cond.	5541	5683	7031	6604	5218	5294
Ammonia-N	0.6	0.85	2.68	1.09	1.44	1.41
Chloride	95	114	88	22	16	15
Fluoride	0.72	0.96	0.81	0.74	0.62	0.68
Sulfate	2641	2683	3348	3484	3093	3107
TD Solids	4661	4895	6051	6429	4879	4965
TS Solids	66	37	47	47	12,599	69
Alkalinity	619	752	836	515	469	457
Acidity	0	2	45	16	22	27
Total Fe	1.14	0.42	0.52	0.34	3.66	0.26
Diss. Fe						
" Ca	38.1	29.9	51.0	83.6	69.2	70.8
" Mg						
" K ₂	1345	1474	1618	1413	1055	1085
" K						
" Mn	0.01	0.01	0.28	0.01	0.12	0.12
" Al	0.46	0.54	0.46	0.33	0.63	0.23
" Cu	0.03	0.02	0.01	0.01	0.07	0.06
" Zn	0.02	0.01	0.02	0.03	0.01	0.03
" Sr	4.19	3.45	6.49	9.35	6.53	4.71
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						
" Hg						

Date 7/20/76

Values in mg/l (except cond., pH, flow, and temp.)

* No Flow

ARCONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 8/3/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306*	307*
Flow, cfs						
Diss. O ₂	8.4	8.8	5.4	9.8	7.3	8.7
pH (field)	7.80	7.70	7.35	7.70	7.70	7.70
pH (lab)	8.11	7.99	7.64	8.06	8.10	7.89
Temp. (H ₂ O)	23	25	20	22	22	24
Temp. (air)						
Cond.	666	365	4084	6194	6097	6038
Ammonia-N	0.01	0.01	0.01	0.01	0.90	0.01
Chloride	17	17	79	25	20	21
Fluoride	0.37	0.25	0.79	0.70	0.61	0.69
Sulfate	203	84	1828	3495	3236	3652
TD Solids	458	235	3356	6357	5696	5666
TS Solids	244	102	144	62	53	70
Alkalinity	137	96	579	461	371	354
Acidity	8	7	44	27	14	29
Total Fe	1.89	1.16	1.24	0.29	0.26	0.19
Diss. Fe						
" Ca	29.4	19.7	56.3	106	99.8	101
" Mg						
" Na	101	38.1	1006	1229	1161	1149
" K						
" Mn	0.02	0.02	0.13	0.04	0.10	0.06
" Al	4.83	1.48	2.30	0.49	0.36	0.56
" Cu	0.00	0.01	0.01	0.00	0.02	0.00
" Zn	0.01	0.02	0.00	0.00	0.00	0.00
" Sr	0.25	0.14	2.39	6.42	6.15	5.95
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						
" Hg						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 8/17/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs						
Diss. O ₂	12.2	8.2	9.2	8.5		8.9
pH (field)	8.00	7.70	7.50	7.70	7.80	7.40
pH (lab)	7.95	7.52	7.49	7.71	7.76	7.54
Temp. (H ₂ O)	24	24	22	23	24	26
Temp. (air)						
Cond.	5498	875	6136	6205	6283	6264
Ammonia-N	1.01	2.34	2.38	0.54	2.00	1.73
Chloride	109	46	99	28	28	24
Fluoride	0.64	0.19	0.70	0.65	0.69	0.66
Sulfate	3049	144	3170	3594	3921	3625
TD Solids	5364	583	5993	6475	6505	6613
TS Solids	206	84	136	59	639	57
Alkalinity	677	273	830	487	489	482
Acidity	40	36	57	41	60	65
Total Fe	1.	0.37	0.86	0.14	2.21	0.15
Diss. Fe						
" Ca	28.3	20.4	38.5	60.0	56.7	61.0
" Mg						
" Na	2078	132	2181	1987	1949	1993
" K						
" Mn	0.06	0.54	0.37	0.12	0.20	0.22
" Al	5.29	0.21	2.83	0.21	6.24	0.21
" Cu	0.01	0.01	0.01	0.04	0.03	0.02
" Zn	0.01	0.01	0.03	0.01	0.01	0.01
" Sr	3.05	0.25	3.86	6.03	5.77	6.28
" Cd						
" Co						
" Cr						
" V						
" Pb						
" Ni						
" Fe						
" Hg						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 8/30/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs						
Diss. O ₂	9.7	10.4	8.0	3.6		9.3
pH (field)	8.00	8.3	7.50	7.70	7.80	7.70
pH (lab)	7.86	8.31	7.54	7.61	7.69	7.81
Temp. (H ₂ O)	21	21	20	18	21	22
Temp. (air)						
Cond.	4699	985	5805	6180	5084	5035
Ammonia-N	0.82	1.38	3.64	0.56	2.16	1.81
Chloride	86	49.59	92	34	27	54
Fluoride	0.79	0.12	0.80	0.67	0.92	0.77
Sulfate	2502	180	3355	3369	3269	3290
TD Solids	4300	713	6050	6880	5465	5239
TS Solids	131	28	40	64	49,948	74
Alkalinity	431	308	854	280	658	354
Acidity	20	0	85	42	57	45
Total Fe	1.65	0.21	0.18	0.32	91.49	0.27
Diss. Fe						
" Ca	29.7	18	34.7	42.4	34.1	42.4
" Mg						
" Na	1143	180	1436	1423	1248	1128
" K						
" Mn	0.20	0.31	0.41	0.28	0.85	0.10
" Al	3.12	0.36	0.62	1.17	0.12	0.10
" Cu	0.01	0.01	0.02	0.02	0.61	0.01
" Zn	0.00	0.01	0.01	0.01	0.03	0.00
" Sr	1.93	0.23	4.58	5.71	0.77	4.93
" Cl	0.010	0.011	0.007	0.042	0.011	0.023
" Co	0.010	0.000	0.010	0.010	0.040	0.010
" Cr	0.000	0.000	0.000	0.000	0.010	0.010
" V						
" Mo						
" Ni	0.370	0.260	0.160	0.290	0.370	0.290
" Pb	0.010	0.050	0.050	0.070	0.060	0.010
" B	0.0004	0.0002	0.0003	0.0008	0.0006	0.0001

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 9/14/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs						
Diss. O ₂	9.2	7.6	5.1	4.1		8.8
pH (field)	7.80	7.50	7.80	7.10	7.40	7.80
pH (lab)	7.93	7.82	8.24	7.86	7.76	8.11
Temp. (H ₂ O)	21.5	22	22	18	19	23
Temp. (air)						
Cond.	1384	1015	4636	3494	2937	3062
Ammonia-N	0.01	2.19	0.18	0.03	1.24	0.96
Chloride	32.0	60.4	71.87	25.83	22.14	21.29
Fluoride	0.84	0.21	0.91	0.73	0.79	0.76
Sulfate	490	123	2461	1953	1929	1641
TD Solids	999	737	4216	3172	3033	2643
TS Solids	76	33	188	117	92.051	60
Alkalinity	229	311	386	216	835	302
Acidity	13	16	4	24	48	14
Total Fe	1.03	0.23	1.12	0.77	0.03	0.14
Diss. Fe						
" Ca	18.0	25	20.0	62.8	71.4	56.7
" Mg						
" Na	286	183	1181	789	713	717
" K						
" Mn	0.04	0.15	0.04	1.81	0.21	0.05
" Al	1.70	0.10	2.63	0.35	0.18	0.35
" Cu	0.00	0.00	0.01	0.01	0.02	0.01
" Zn	0.00	0.01	0.01	0.00	0.03	0.01
" Sr	0.33	0.32	1.40	2.94	4.09	2.83
" Cd						
" Co						
" Cr						
" V						
" Pb						
" Ni						
" Fe						
" Hg						

Date 9/28/76

Values in mg/l (except cond., pH, flow, and temp.)

	301	302	303	305	Sampling Sites 306	307
Parameter:						
Flow, cfs						
Diss. O ₂	9.3	9.2	5.7	8.4		9.4
pH (field)	7.20	7.1	7.10	7.50	7.50	7.20
pH (lab)	7.79	8.12	8.07	7.78	8.10	7.97
Temp. (H ₂ O)	17	18	17	16	17	19
Temp. (air)						
Cond.	1898	770	2363	1715	3413	3474
Ammonia-N	7.22	1.37	0.08	0.03	5.04	2.11
Chloride	78.7	28.4	36.2		13.5	17.7
Fluoride	0.71	0.32	0.69	0.42	0.61	0.65
Sulfate	555	216	1099	858	1905	1930
TD Solids	1389	558	1847	1366	3149	3060
TS Solids	94	247	287	43	53,380	66
Alkalinity	181	170	165	92	807	296
Acidity	18	5	5	9	9	11
Total Fe	1.33	7.45	7.62	0.27	0.09	0.44
Diss. Fe						
" Ca	44.4	22.14	20.1	63.3	52.9	72.8
" Mg						
" Na	340	166	630	338	953	739
" K						
" Mn	0.09	0.11	0.07	0.07	0.08	0.11
" Al	2.06	4.44	6.13	0.28	0.10	0.43
" Cu	0.01	0.00	0.01	0.00	0.00	0.00
" Zn	0.01	0.01	0.02	0.02	0.01	0.01
" Sr	1.75	0.33	0.85	2.15	3.94	3.96
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						

Values in mg/l (except cond., pH, flow, and temp.)

[illegible]

Date 10/25/76

Values in mg/l. (except cond., pH, flow, and temp.)

	301	302	303	305	Sampling Sites 306	307
Parameter						
Flow, cfs						
Diss. O ₂	9.8	9.8	9.0	8.7	9.5	9.3
pH (field)	7.10	7.60	7.60	6.90	7.00	7.10
pH (lab)	7.46	7.88	7.97	7.71	7.93	7.98
Temp. (H ₂ O)	8.0	7.0	8.0	7.0	8.5	8.5
Temp. (air)						
Cond.	570	716	1303	2824	4116	3356
Ammonia-N	0.17	0.44	0.08	0.04	1.61	2.09
Chloride	24.7	36.4	26.9	24.1	21.0	19.7
Fluoride	0.58	0.50	0.73	0.71	0.96	1.02
Sulfate	226	221	722	2002	2927	2273
TD Solids	500	609	1157	3077	4635	3665
TS Solids	81	70	133	57	48	36
Alkalinity	112	217	114	151	418	358
Acidity	39	23	9	16	23	18
Total Fe	2.75	1.74	4.75	0.75	0.19	0.39
Diss. Fe						
" Ca	31.3	30.0	22.1	91.2	83.6	79.7
" Mg						
" Na	85.7	126	292	547	1002	784
" K						
" Mn	0.13	0.24	0.04	0.12	0.65	0.39
" Al	0.81	0.13	5.70	3.12	0.30	2.48
" Cu	0.02	0.02	0.04	0.01	0.00	0.03
" Zn	0.00	0.01	0.02	0.01	0.01	0.01
" Sr	0.26	0.31	0.44	4.56	4.81	3.85
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 11/8/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs			DRY			
Diss. O ₂	10.6	11.6		10.2		10.4
pH (field)	7.40	6.80		7.30	6.90	7.20
pH (lab)	8.26	7.82		7.48	7.76	7.63
Temp. (H ₂ O)	7.7	10.2		6.0	9.5	8.6
Temp. (air)						
Cond.	966	945		2750	4409	4072
Ammonia-N	0.47	0.68		0.14	2.73	1.95
Chloride	43.7	41.0		30.4	43.3	20.9
Fluoride	0.45	0.25		0.58	0.91	0.98
Sulfate	346	232		1723	2676	2712
TD Solids	725	693		2745	5061	4290
TS Solids	24	14		563	39,414	58
Alkalinity	124	295		227	677	385
Acidity	3	28		35	45	44
Total Fe	0.34	0.23		0.42	0.25	0.18
Diss. Fe						
" Ca	51.1	34.2		101	90.7	92.0
" Mg						
" Na	130	144		521	1072	973
" K						
" Mn	0.16	0.37		0.78	0.28	0.84
" Al	0.45	0.02		0.47	0.22	0.13
" Cu	0.01	0.00		0.02	0.02	0.01
" Zn	0.01	0.01		0.01	0.02	0.01
" Sr	0.50	0.40		3.63	4.78	4.27
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						
" Hg						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 11/22/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs			DRY			
Diss. O ₂	12.6	15.0		11.9		10.8
pH (field)	6.90	7.30		6.80	7.00	7.10
pH (lab)	8.07	8.29		7.12	7.71	7.82
Temp. (H ₂ O)	2	5		4	5	7
Temp. (air)						
Cond.	1092	836		4540	3664	3535
Ammonia-N	0.03	0.52		0.03	2.17	2.21
Chloride	44.8	58.9		19.8	28.7	16.5
Fluoride	0.46	0.18		0.50	1.21	1.16
Sulfate	414	175		3598	2804	2552
TD Solids	954	707		5959	4538	4105
TS Solids	29	66		83	71,285	72
Alkalinity	284	320		369	883	378
Acidity	24	3		102	59	54
Total Fe	0.29	0.27		0.64	0.03	0.20
Diss. Fe						
" Ca	34.9	24.8		78.9	71.9	67.4
" Mg						
" Na	255	140		1046	1045	945
" K						
" Mn	0.20	0.61		2.06	0.28	0.65
" Al	0.53	0.05		0.86	0.05	0.43
" Cu	0.02	0.00		0.02	0.01	0.02
" Zn	0.01	0.00		0.05	0.02	0.01
" Sr	0.65	0.44		5.12	5.28	4.58
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code)

Date 12/ 6/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs						
Diss. O ₂	11.8	13.1	11.7	11.3		12.3
pH (field)	7.30	8.00	7.40	7.20	7.00	6.80
pH (lab)	7.72	7.97	8.03	7.61	7.86	7.89
Temp. (H ₂ O)	1	2	1	1	1	3
Temp. (air)						
Cond.	1167	819	955	2254	4518	4869
Ammonia-N	0.09	3.84	0.56	0.28	5.81	5.78
Chloride	45.4	58.1	21.6	22.3	18.5	13.4
Fluoride	0.36	0.17	0.47	0.39	0.78	0.82
Sulfate	530	182	527	1557	3046	3208
TD Solids	1096	742	895	2407	5773	5878
TS Solids	108	57	224	77	57,879	139
Alkalinity	275	356	105	170	591	540
Acidity	24	24	9	25	61	53
Total Fe	1.32	0.80	5.30	1.61	0.18	0.85
Diss. Fe						
" Ca	34	27	29.9	55	57.2	56.3
" Mg						
" Na	227	140	210	374	1148	1195
" K						
" Mn	0.30	1.72	0.12	0.58	0.66	1.01
" Al	0.66	0.04	1.87	0.59	0.13	0.06
" Cu	0.00	0.00	0.02	0.01	0.01	0.02
" Zn	0.01	0.02	0.02	0.03	0.04	0.02
" Sr	0.89	0.56	0.70	3.26	6.39	6.77
" Cd	0.002	0.012	0.020	0.016	0.009	0.013
" Co	0.011	0.004	0.003	0.002	0.023	0.004
" Cr	0.005	0.016	0.014	0.011	0.010	0.010
" V						
" Pb						
" Ni	0.003	0.004	0.004	0.003	0.067	0.014
" Pb	0.095	0.004	0.055	0.028	0.007	0.036
" Hg	0.0003	0.0011	0.0006	0.0012	0.0010	0.0005

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 12/20/76

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs			DRY			
Diss. O ₂	12.4	14.0		12.2		10.8
pH (field)	7.40	7.60		7.40	7.10	7.00
pH (lab)	8.19	8.08		7.53	7.77	7.82
Temp. (H ₂ O)	5	4		3	5	7
Temp. (air)						
Cond.	1247	1076		2461	6468	6132
Ammonia-N	0.04	1.60		0.10	4.01	2.49
Chloride	44.6	55.8		21.4	19.0	13.2
Fluoride	0.39	0.16		0.38	0.98	0.78
Sulfate	356	195		1532	2637	3002
TD Solids	949	675		2365	6414	6911
TS Solids	16	26		8	24, 114	41
Alkalinity	315	333		166	596	449
Acidity	8	17		52	56	92
Total Fe	0.46	0.39		0.30	2.46	0.23
Diss. Fe						
" Ca	23.4	18.6		36.0	41.8	42.0
" Mg						
" Na	185	128		459	1402	1257
" K						
" Mn	0.08	0.60		0.88	0.32	0.66
" Al	0.64	0.05		0.76	0.19	0.07
" Cu	0.04	0.01		0.02	0.14	0.02
" Zn	0.01	0.01		0.03	0.03	0.03
" Sr	0.73	0.59		3.02	7.11	8.10
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						
" Hg						

Values in mg/l (except cond., pH, flow, and temp.)

[illegible]

Date 2/15/77

Values in mg/l (except cond., pH, flow, and temp.)

[illegible]

Values in mg/l (except cond., pH, flow, and temp.)

	301	302	303	305	Sampling Sites 306	307
Parameter						
Flow, cfs	2.96	3.12	0.12	0.07		
Diss. O ₂	9.8	9.5	9.2	9.4		11.0
pH (field)	7.80	7.90	7.60	7.50		7.30
pH (lab)	7.09	7.62	7.64	7.50		7.96
Temp. (H ₂ O)	7	11	9	7		10
Temp. (air)						
Cond.	460	306	892	1223		2128
Ammonia-N	0.37	0.63	0.027	1.05		1.03
Chloride	24.12	16.97	18.58	20.86		22.06
Fluoride	0.74	0.23	0.40	0.46		1.01
Sulfate		105	499	842		2638
TDS Solids	401	262	1208			
TDS Solids	242	67	209	8		30
Alkalinity	92	93	88	132		402
Acidity	53	14	24	25		57
Total Fe	5.21	3.09	11.42	0.37		0.167
Diss. Fe						
" Ca	16.3	15	9.63	88		84
" Mg						
" Na	62	43	212	201		1235
" K						
" Mn	0.24	0.438	0.164	0.30		0.26
" Al	6.26	1.86	15.23	0.64		0.43
" Cu	0.014	0.008	0.023	0.00		0.021
" Zn	0.021	0.015	0.034	0.044		0.007
" Sr	0.065	0.107	0.124	1.60		4.26
" Cd						
" Co						
" Cr						
" V						
" Mo						
" Ni						
" Pb						
" Hg						

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 4/12/77

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites						
	301	302	303	304	305	306	307
Flow, cfs	3.89	0.22	DRY		DRY		
Diss. C ₂	11.8	16.0		11.2		9.5	
pH (field)	7.5	8.1		7.4		7.5	
pH (lab)	7.96	9.07		8.47		8.12	7.51
Temp. (H ₂ O)	21	22		22		22	21
Temp. (air)							
Cond.	2002			1229		3744	3869
Ammonia-N	0.05	1.41		1.15		3.28	1.90
Chloride	71.68	40.33		139.34		58.06	22.20
Fluoride	3.15	0.26		0.89		1.06	1.00
Sulfate	829	772		47		1117	2104
TD Solids	1541	1482		990		3442	3429
TS Solids	72.4	50.0		18.8		429.6	47.6
Alkalinity	354	264		178		390	466
Acidity	23	0		0		37	82
Total Fe	1.15	0.31		0.19		1.05	0.33
Diss. Fe							
" Ca	18	17		44		38	80.7
" Mg							
" Na	604	94		329		101	922
" K							
" Mn	0.20	0.29		0.13		0.13	0.83
" Al	5.97	1.69		1.43		0.99	0.53
" Cu	0.020	0.003		0.005		0.008	0.015
" Zn	0.022	0.040		0.00		0.009	0.011
" Sr	4.16	0.51		1.95		8.63	8.38
" Cd							
" Co							
" Cr							
" V							
" Mo							
" Ni							
" Pb							

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____

Date 3/15/77

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites					
	301	302	303	305	306	307
Flow, cfs	3.52	1.16	0.14	0.07		
Diss. O ₂	10.2	7.8	9.6	10.6		12.0
pH (field)	7.70	7.80	7.50	7.80	7.00	7.00
pH (lab)	7.44	7.58	7.81	7.68	7.77	8.02
Temp. (H ₂ O)	17	21	18	17	17	18
Temp. (air)						
Cond.	1068	533	1259	2296	4214	4648
Ammonia-N	0.33	0.60	0.015	1.49	3.10	1.40
Chloride	22.78	17.15	19.11	20.19	20.81	21.43
Fluoride	0.72	0.22	0.44	0.44	0.18	0.98
Sulfate	349	205	575	1075	2641	2497
TD Solids	615	289	865	1702	4571	4642
TS Solids	111	67	64	24	21,243	38
Alkalinity	77	122	95	220	272	375
Acidity	16	23	9	23	47	38
Total Fe	3.29	1.24	8.15	0.062	0.096	0.045
Diss. Fe						
" Ca	17	16.0	9.74	89	36.0	81
" Mg						
" Na	1520	76	468	416	437	1235
" K						
" Mn	0.134	0.069	0.207	0.149	0.252	0.299
" Al	5.99	1.83	14.39	0.745	0.997	0.44
" Cu	0.003	0.00	0.08	0.003	0.00	0.003
" Zn	0.029	0.018	0.037	0.043	0.027	0.008
" Sr	0.11	0.15	0.16	1.65	1.96	4.64
" Cd	0.028	0.039	0.047	0.041	0.029	0.043
" Co	0.109	0.008	0.167	0.095	0.276	0.201
" Cr	0.009	0.009	0.041	0.009		0.051
" V						
" Pb						
" Ni	0.011	0.000	0.010	0.072	0.754	0.164
" Fe	0.009	0.059	0.014	0.047	0.050	0.024
" Hg	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 3/31/77

Values in mg/l (except cond., pH, flow, and temp.)

	301*	302	303	304	Sampling Sites 305 306		307				
Parameter											
Flow, cfs	4.12	0.78	DRY								
Diss. O ₂	9.6	8.6		8.8	10.0		11.4				
pH (field)	7.5	7.9		7.7	7.9	6.9	6.9				
pH (lab)	7.39	7.48		7.60	7.66	7.90	8.03				
Temp. (H ₂ O)	14	18		16	13	14	17				
Temp. (air)											
Cond.	2056			1387	2055	3838	3974				
Ammonia-N	0.33	0.55		0.031	1.04	3.10	1.03				
Chloride	22.15	17.42		18.76	20.19	19.61	21.17				
Fluoride	0.74	0.18		0.40	0.45	0.15	0.90				
Sulfate	826	767		8	774	1418	2390				
TD Solids	1453	1490		918	1234	3975	3972				
TS Solids	39	24		38	13	39	34				
Alkalinity	37	126		106	203	327	312				
Acidity	51	39		45	45	51	16				
Total Fe	0.82	2.29		2.51	0.27	0.80	0.36				
Diss. Fe											
" Ca	17	16		44	96	38	81.3				
" Mg											
" Na	312	203		429	468	490	1285				
" K											
" Mn	0.33	0.15		0.13	0.13	0.38	0.32				
" Al	5.51	1.64		0.87	0.59	0.94	0.34				
" Cu	0.03	0.02		0.02	0.01	0.02	0.03				
" Zn	0.013	0.013		0	0.020	0.018	0.013				
" Sr	0.12	0.14		0.16	1.68	1.94	3.99				
" Cd											
" Co											
" Cr											
" V											
" Hb											
" Ni											
" Pb											
" H-											

being pumped in from the pit.

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 4/27/77

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites						
	301	302	303	304	305	306	307
Flow, cfs	2.43	0.10	DRY		DRY		
Diss. O ₂	12.2	14.1		10.6		11.0	
pH (field)	7.5	7.8		7.3		7.4	7.5
pH (lab)	8.01	5.89		6.65		7.92	7.81
Temp. (H ₂ O)	14	20		20		16	18
Temp. (air)							
Cond.	5777	1177		3355			7310
Ammonia-N	0.37	3.20		0.98		2.55	0.15
Chloride	81.86	51.76		173.72		66.59	26.89
Fluoride	0.64	0.20		0.71		1.01	0.80
Sulfate	2805	1323		1264		4163	49
TD Solids	4635	864		2362		6650	5984
TS Solids	74.0	26.4		5.6		62,848	
Alkalinity	306	48		112		515	395
Acidity	18	162		64		15	28
Total Fe	0.54	0.30		0.15		0.14	0.16
Diss. Fe							
" Ca	71	56		56		92	95
" Mg							
" Na	1117.1	158		549		1306	1061
" K							
" Mn	0.06	0.04		0.11		0.31	0.28
" Al	3.35	2.19		4.19		1.94	4.50
" Cu	0.005	0.011		0.012		0.014	0.012
" Zn	0	0		0		0	0
" Sr	3.56	0.50		2.10		7.71	6.95
" Cd							
" Co							
" Cr							
" V							
" Pb							
" Ni							
" Fe							
" Hg							

Mine Name (and/or code) _____ Date 5/9/77

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Values in mg/L (except conductivity)						
	301	302	303	304	Sampling Sites 305	306	307
Flow, cfs	7.31	0.11	DRY		DRY		
Diss. O ₂	9.9	14.0		8.5		8.4	
pH (field)	7.2	7.9		7.6		7.5	7.5
pH (lab)	7.70	8.21		8.08		7.69	7.60
Temp. (H ₂ O)	17	21		22		18	21
Temp. (air)							
Cond.	6210	876		2897		6157	6264
Ammonia-N	0.37	2.84		0.78		257	0.15
Chloride	72.35	48.72		143.81		71.50	45.36
Fluoride	0.57	0.19		0.65		0.88	0.75
Sulfate	2968	201		1276		3121	2760
TD Solids							
TS Solids	26.8	8.4		5.2		78.916	17.2
Alkalinity	376	290		169		373	495
Acidity	89	0		18		102	99
Total Fe	0.37	0.15		0.02		0.11	0.19
Diss. Fe							
" Ca	43	22.3		27		84.2	21.2
" Mg							
" Na	1174	173		554		1310	1267
" K							
" Mn	0.05	0.03		0.02		0.15	0.10
" Al	3.36	2.17		3.89		1.94	4.45
" Cu	0.07	0.01		0.01		0.02	0.02
" Zn	0.01	0.01		0.003		0.03	0.01
" Sr	3.46	0.39		2.06		7.92	7.10
" Cd							
" Co							
" Cr							
" V							
" Pb							
" Ni							
" Fe							
" U							

Date 5/23/77

Values in mg/l (except cond., pH, flow, and temp.)

[illegible]

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 6/6/77

Values in mg/l (except cond., pH, flow, and temp.)

Parameter	Sampling Sites						
	301	302	303	304	305	306	307
Flow, cfs	8.30	0.01	DRY		DRY		
Diss. O ₂	8.4	9.0		8.1		7.6	7.6
pH (field)	7.3	8.0		7.6		7.3	7.7
pH (lab)	7.51	8.22		8.30		7.62	7.61
Temp. (H ₂ O)	26	27		28		25	27
Temp. (air)							
Cond.	6913	1022		3982		7302	7585
Ammonia-N	2.00	0.405		0.30		3.99	3.28
Chloride	116.12	69.71		203.65		58.86	28.81
Fluoride	0.36	0.135		0.415		0.59	0.52
Sulfate	1331	198		1530		1909	1988
TD Solids	6056	707		2868		6709	6614
TS Solids	78.4	45.2		26.4		1574.0	67.6
Alkalinity	448	301		243		439	543
Acidity	84.	0		0		115	88
Total Fe	0.187	0.097		0.061		0.036	0.191
Diss. Fe							
" Ca	60	30		35.5		73.3	88
" Mg							
" Na	1556	206		766		867	1510
" K							
" Mn	0.095	0		0		0.015	0.023
" Al	1.009	1.065		0.392		0.729	0.672
" Cu	0.028	0.020		0.023		0.032	0.013
" Zn	0.016	0.001		0.005		0.003	0.025
" Sr	4.52	0.39		1.93		7.03	6.81
" Cd	0.010	0.013		0.012		0.038	0.012
" Co	0.008	0.008		0.002		0.092	0.011
" Cr	0.000	0.001		0.001		0.002	0.001
" V							
" Mo							
" Ni	0.023	0.005		0.002		0.180	0.015
" Pb	0.027	0.013		0.022		0.030	0.183

ARGONNE NATIONAL LABORATORY - ECT Water Data

Mine Name (and/or code) _____ Date 6/20/77

Values in mg/l. (except cond., pH, flow, and temp.)

Parameter	Sampling Sites						
	301	302	303	304	305	306	307
Flow, cfs	4.10	0.02	DRY		DRY		
Diss. O ₂	7.9	11.6		8.4		8.4	
pH (field)	7.3	7.9		7.7		7.4	7.6
pH (lab)	7.43	8.09		8.22		7.69	7.49
Temp. (H ₂ O)	25	28		28		24	26
Temp. (air)							
Cond.	6276	938		4225		5791	
Ammonia-N	0.142	1.98		0.048		3.100	2.30
Chloride	116.12	76.82		251.44		59.62	26.30
Fluoride	0.685	0.182		0.840		4.20	0.940
Sulfate	1274	227		1676		2469	951
TD Solids	6003	839		3439		6324	6246
TS Solids	73.2	30.8		178.0		248.8	59.2
Alkalinity	511	301		224		493	423
Acidity	679	50		0		431	1223
Total Fe	0.302	0.029		0.073		0.015	0.007
Diss. Fe							
" Ca	127	39		58.7		140	165
" Mg							
" Na	1233	205		789		1210	1051
" K							
" Mn	0.005	0.019		0		0.237	0.403
" Al	0.747	0.469		0.278		0.395	0.088
" Cu	0.003	0.006		0.004		0.050	0.001
" Zn	0.015	0.006		0.001		0	0.012
" Sr	4.097	0.418		2.244		6.348	6.490
" Cd							
" Co							
" Cr							
" V							
" Hb							
" Ni							
" Pb							
" Hg							

Date 7/5/77

Values in mg/l (except cond., pH, flow, and temp.)

[illegible]

Appendix F

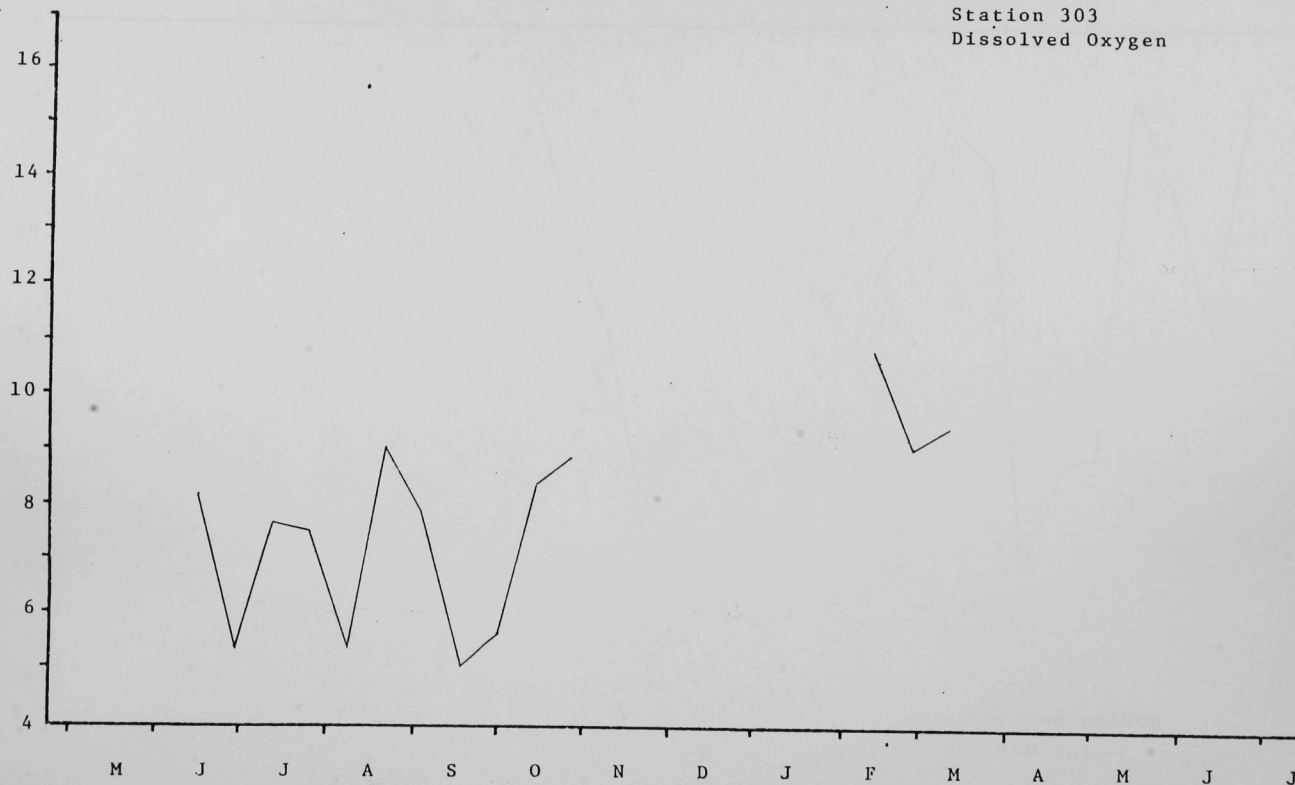
Graphs of Water Quality Parameters as a Function of Time

3/1

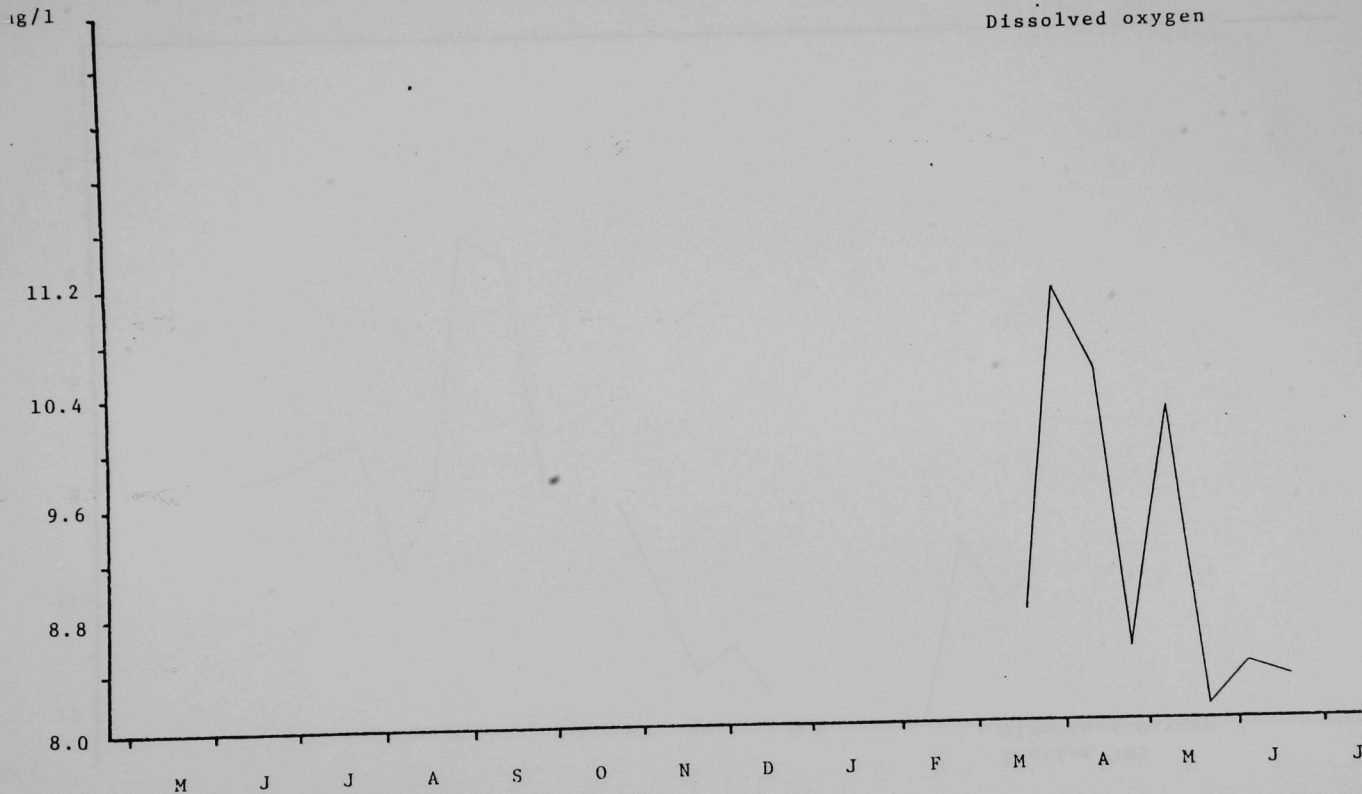
Station 302
Dissolved Oxygen



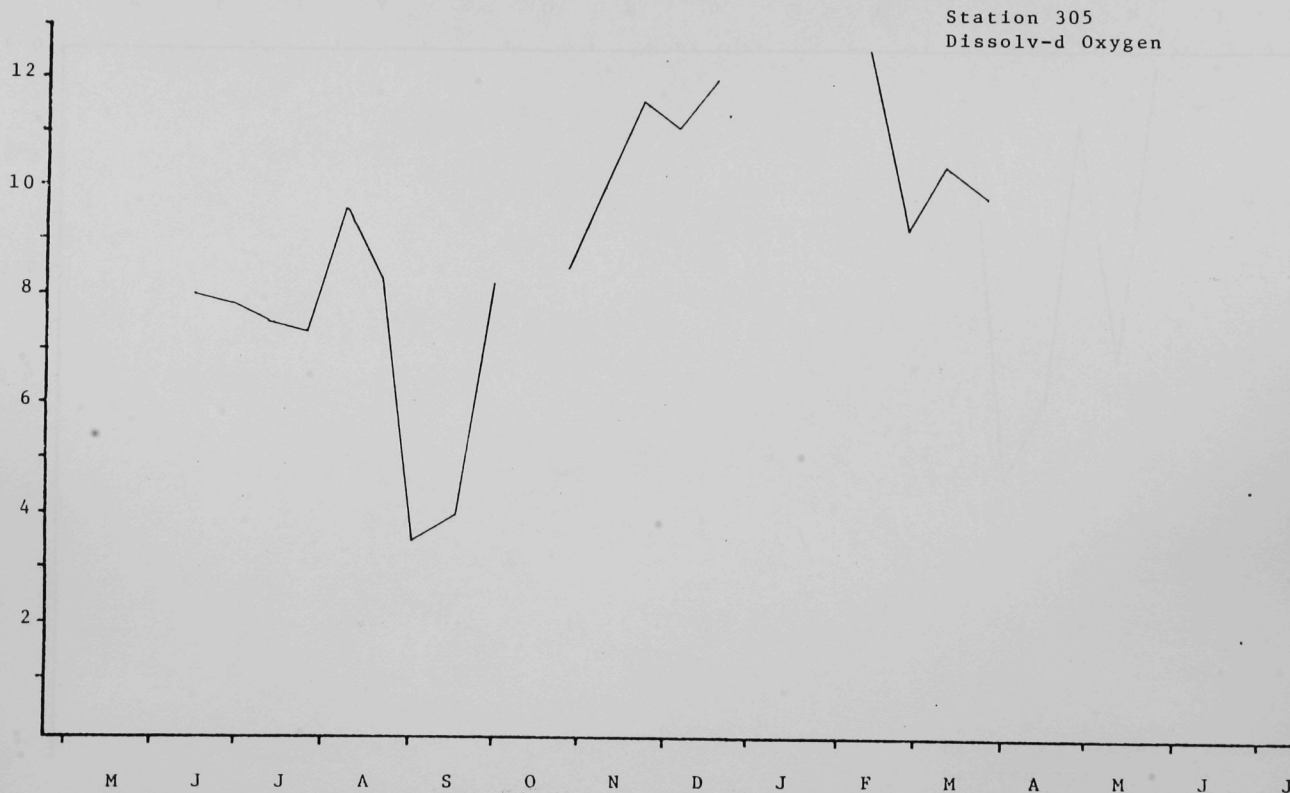
mg/l



Station 304
Dissolved oxygen

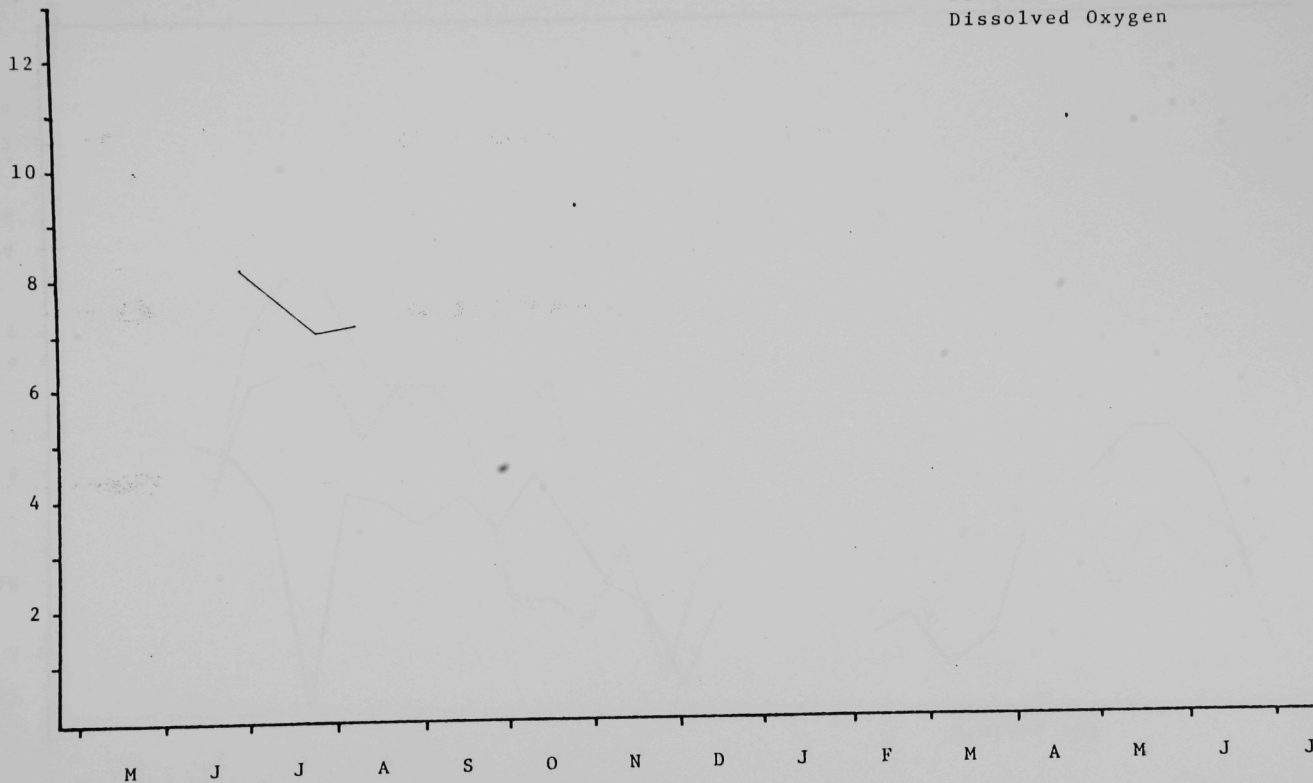


mg/l

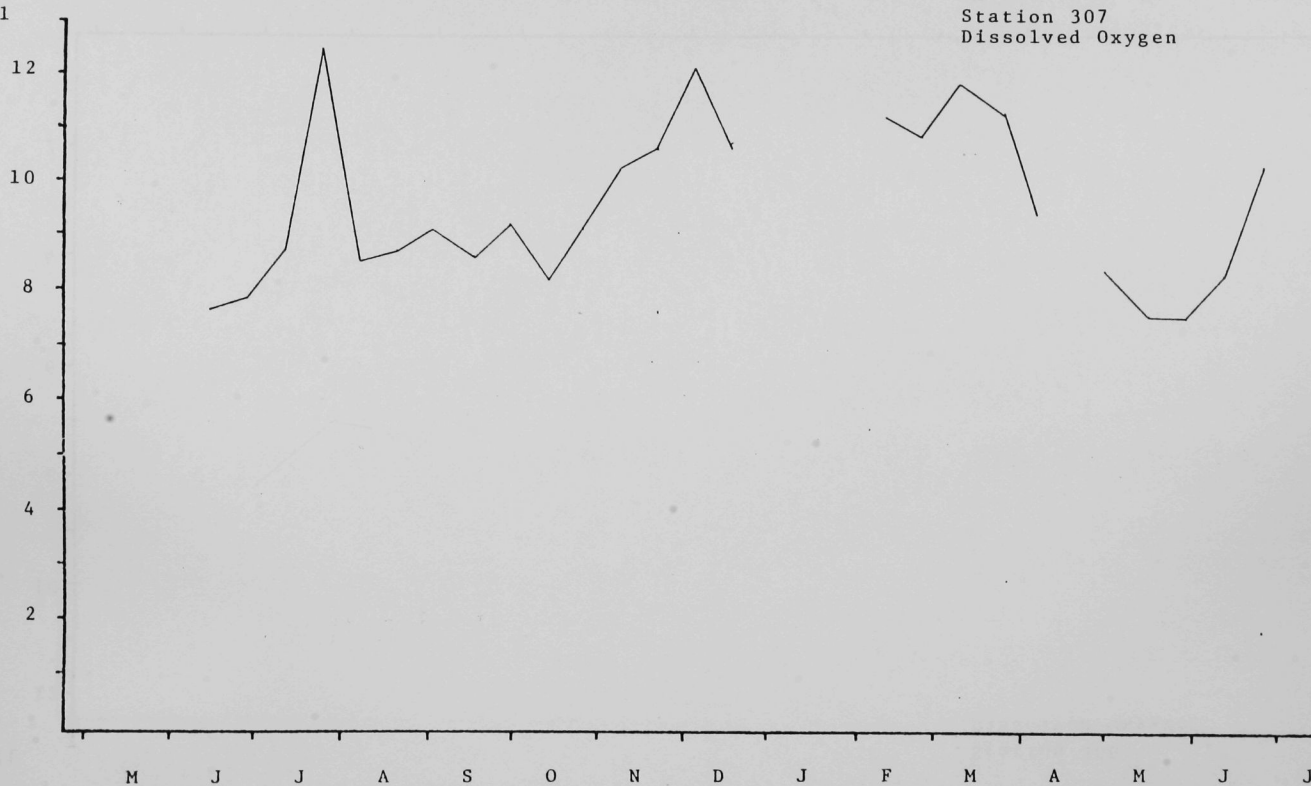


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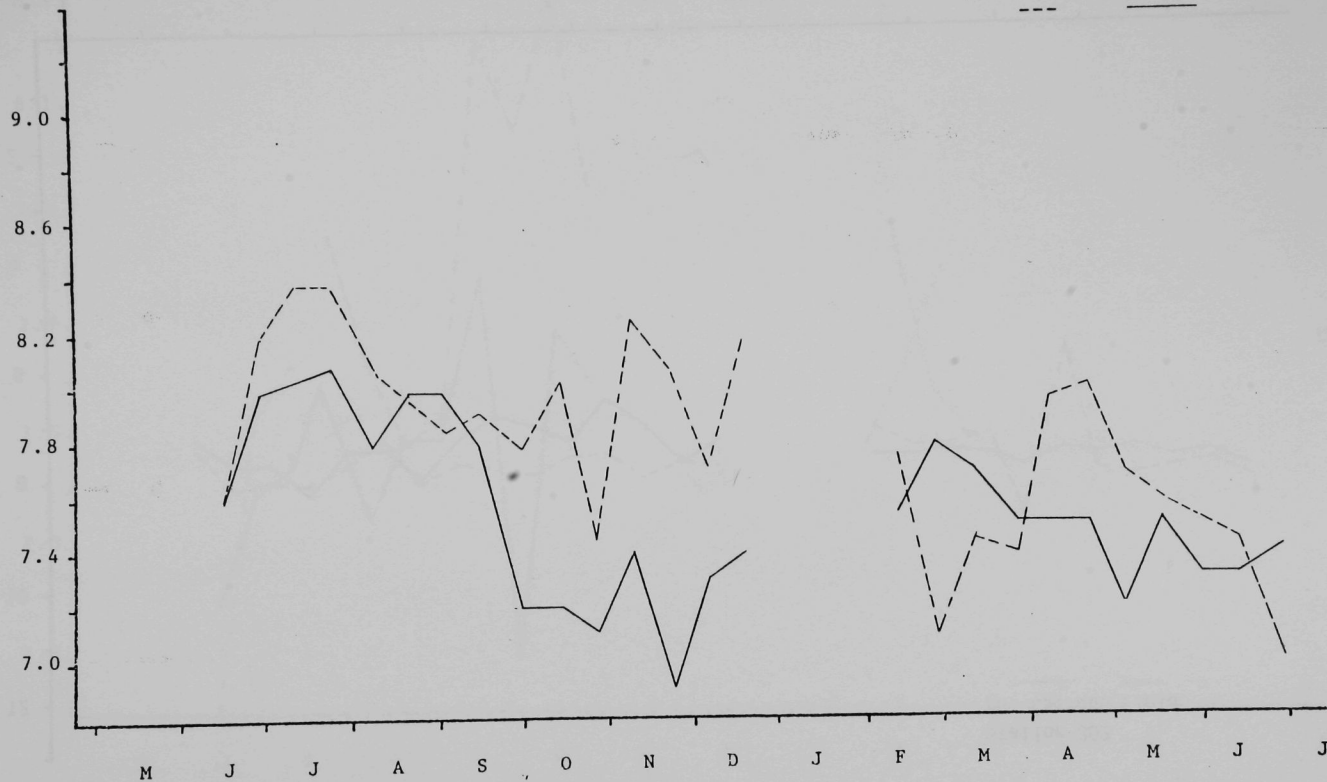
Station 306
Dissolved Oxygen

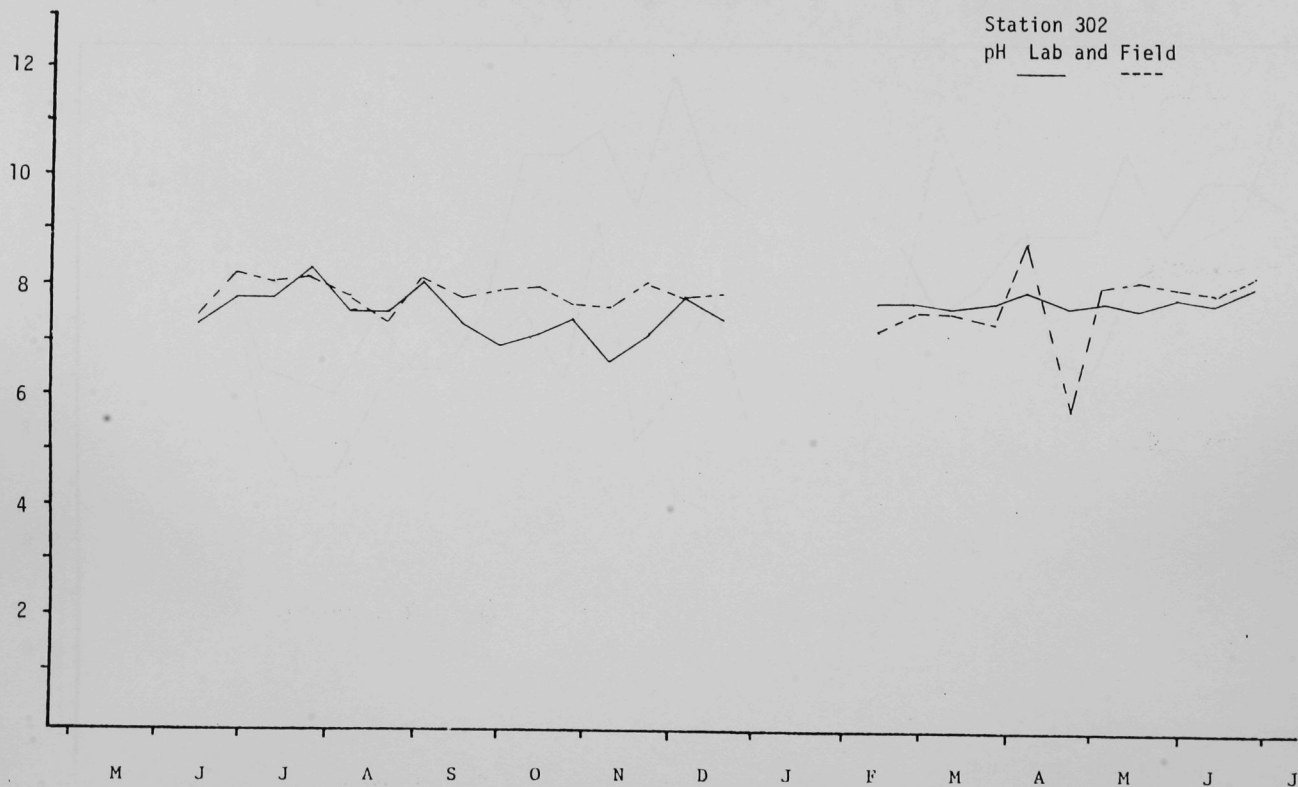


mg/l

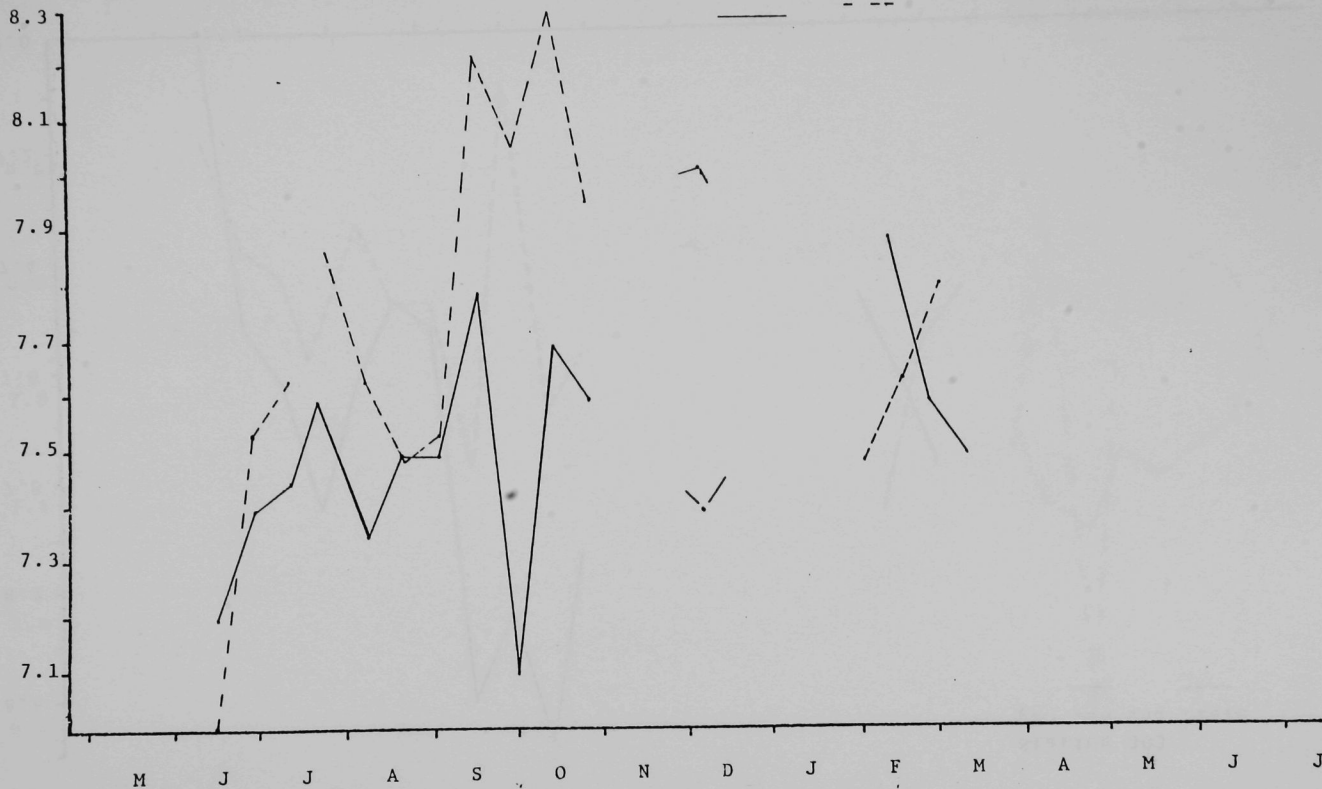


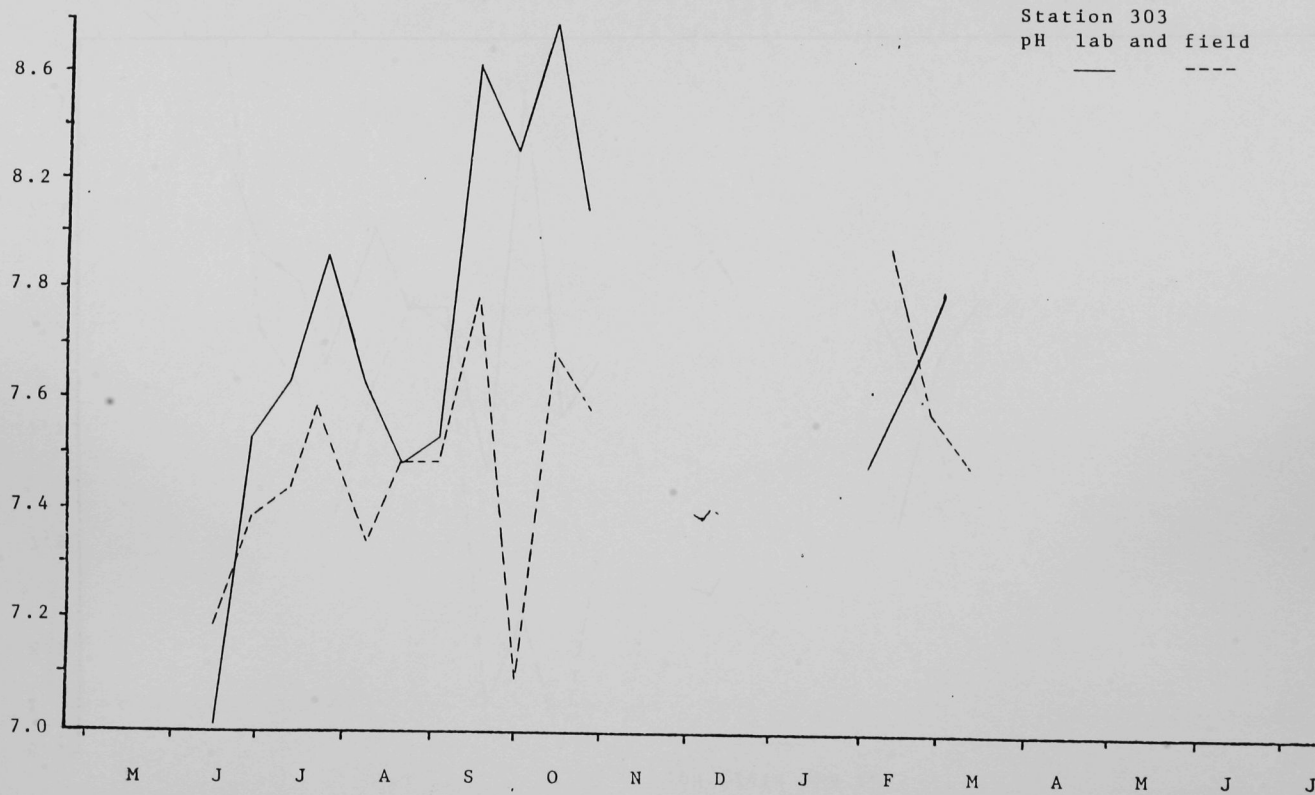
Station 301
pH Lab and field



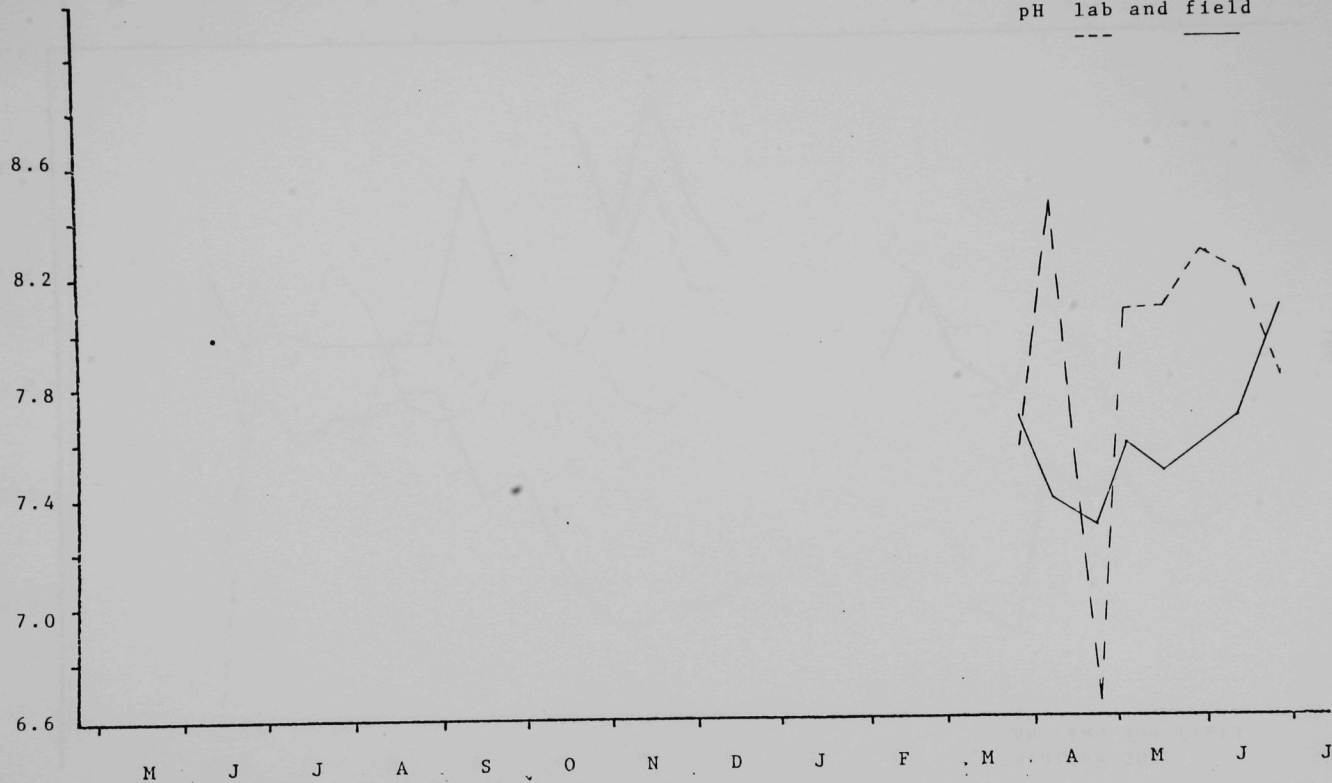


Station 303
pH field and lab



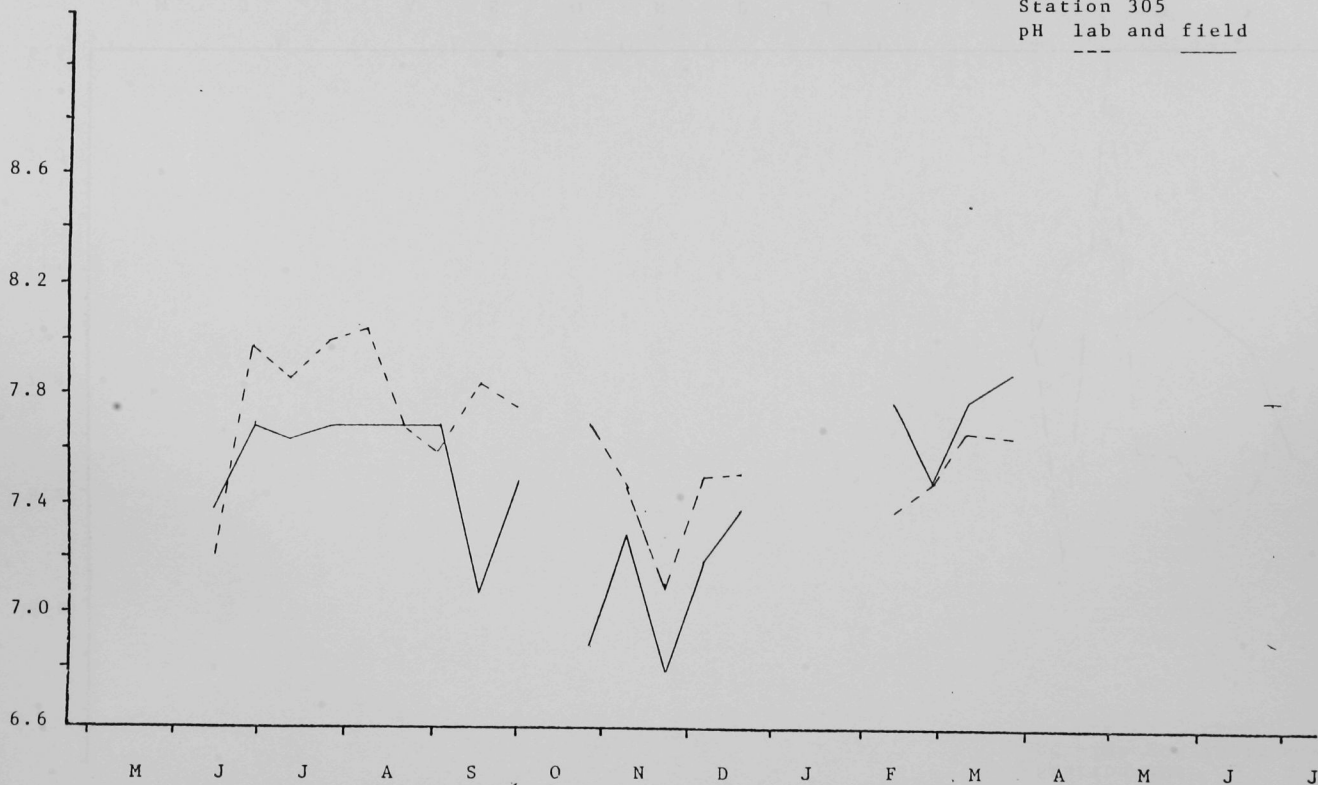


Station 304
pH lab and field



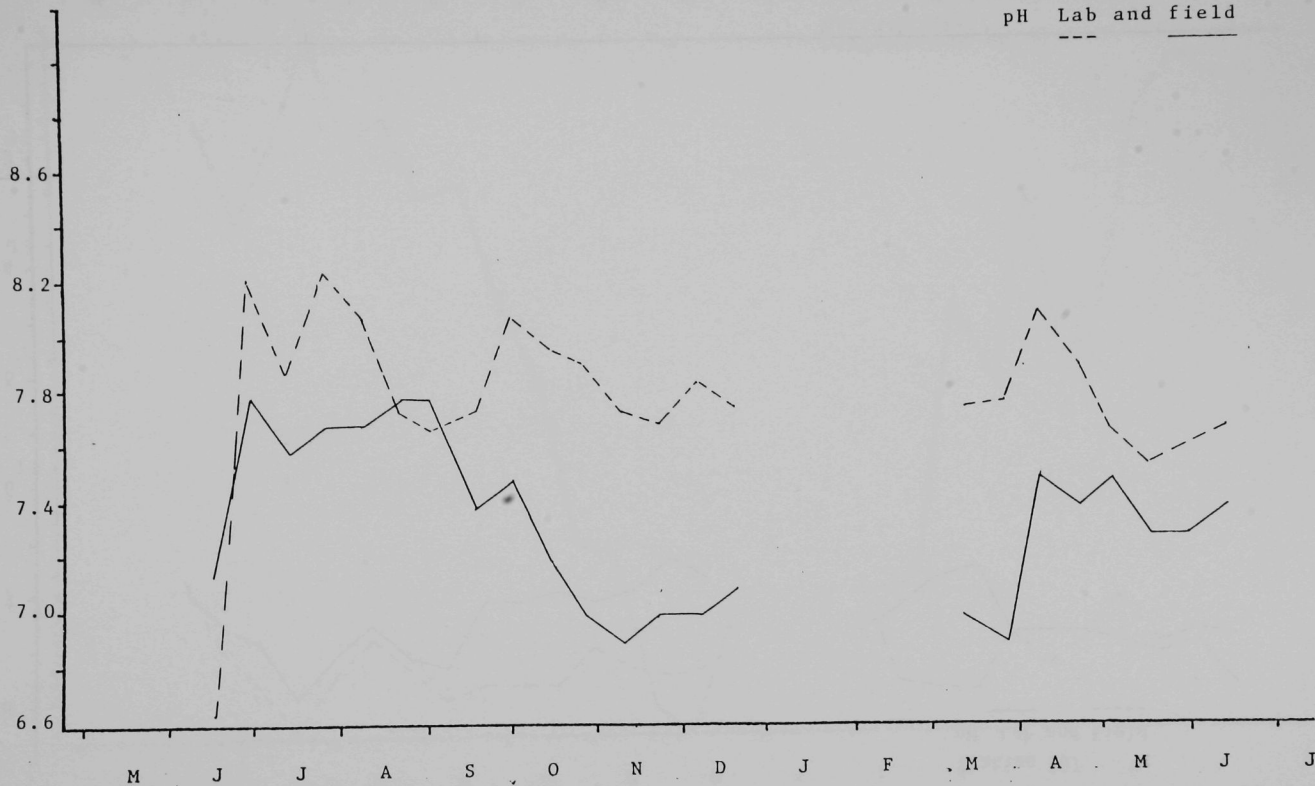
Station 305

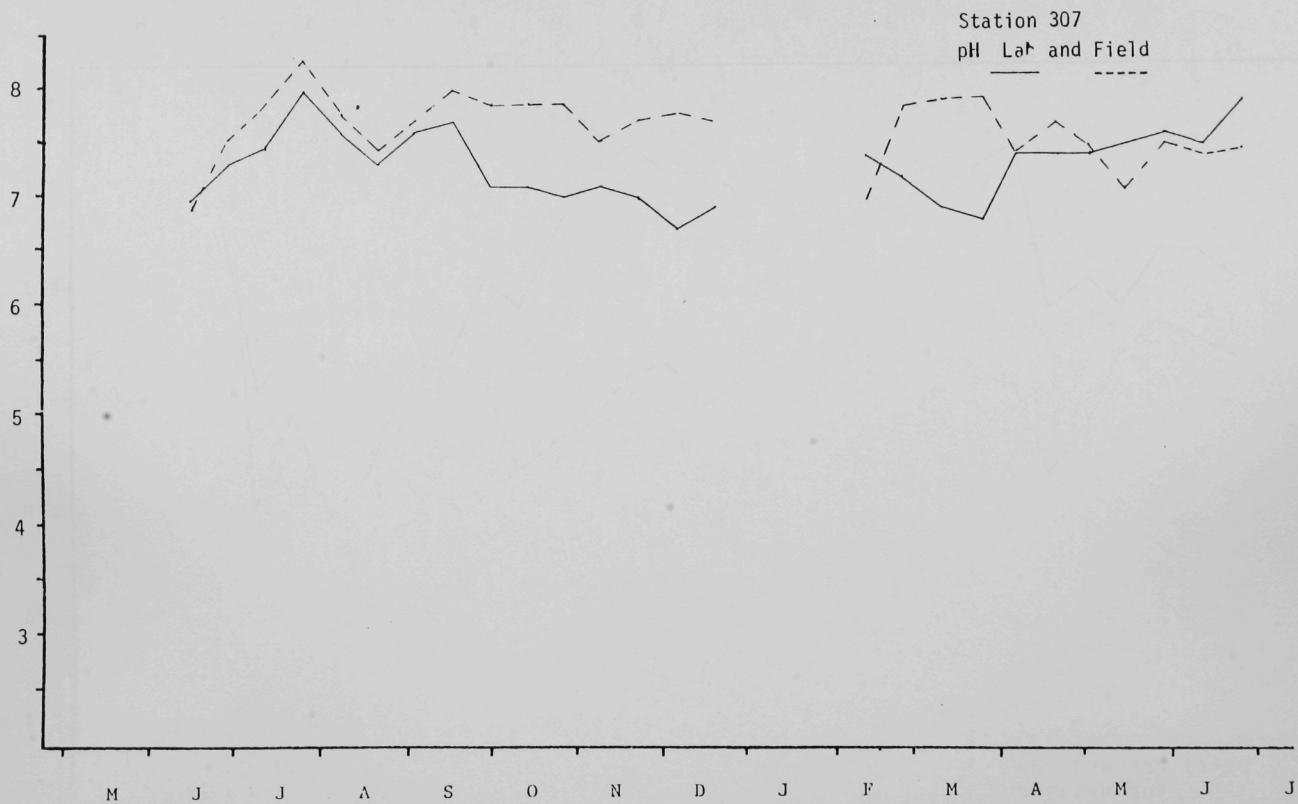
pH lab and field

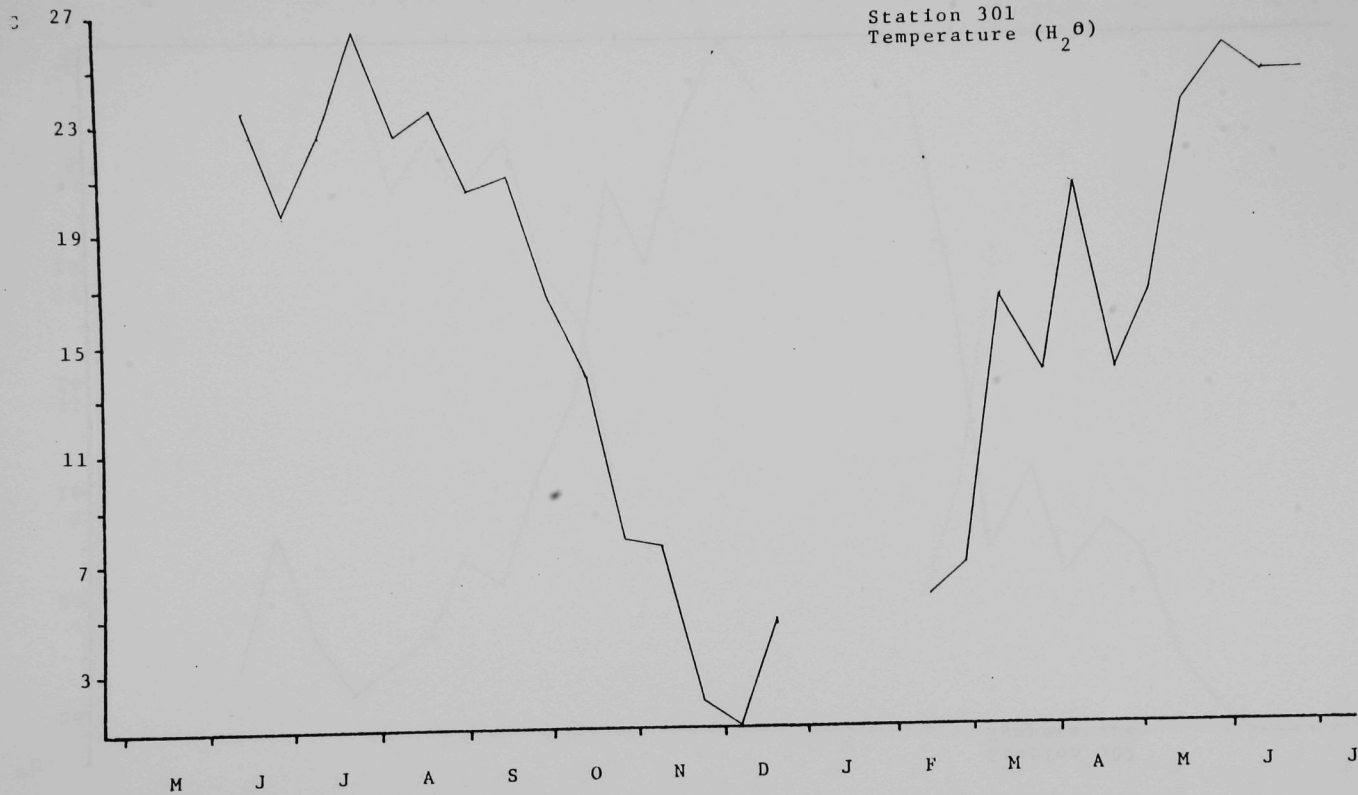


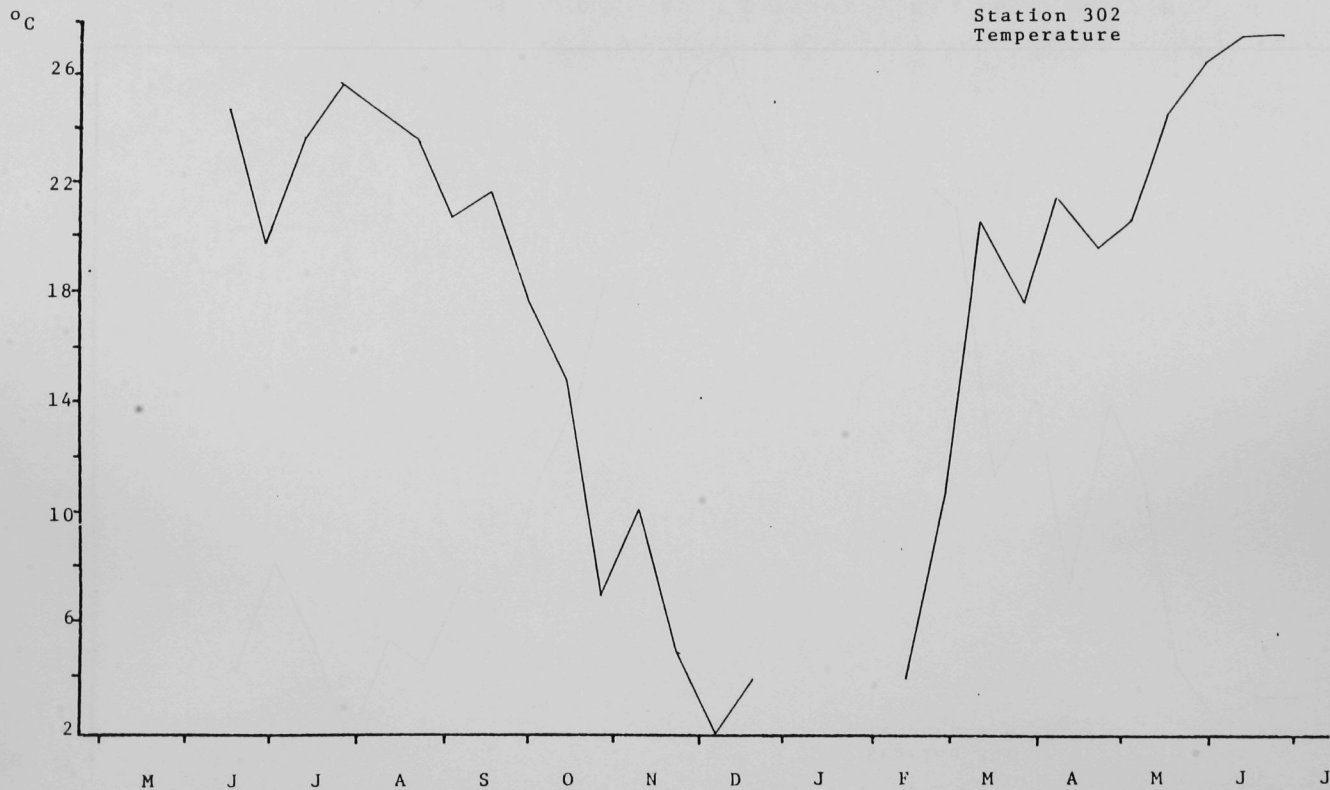
Station 306

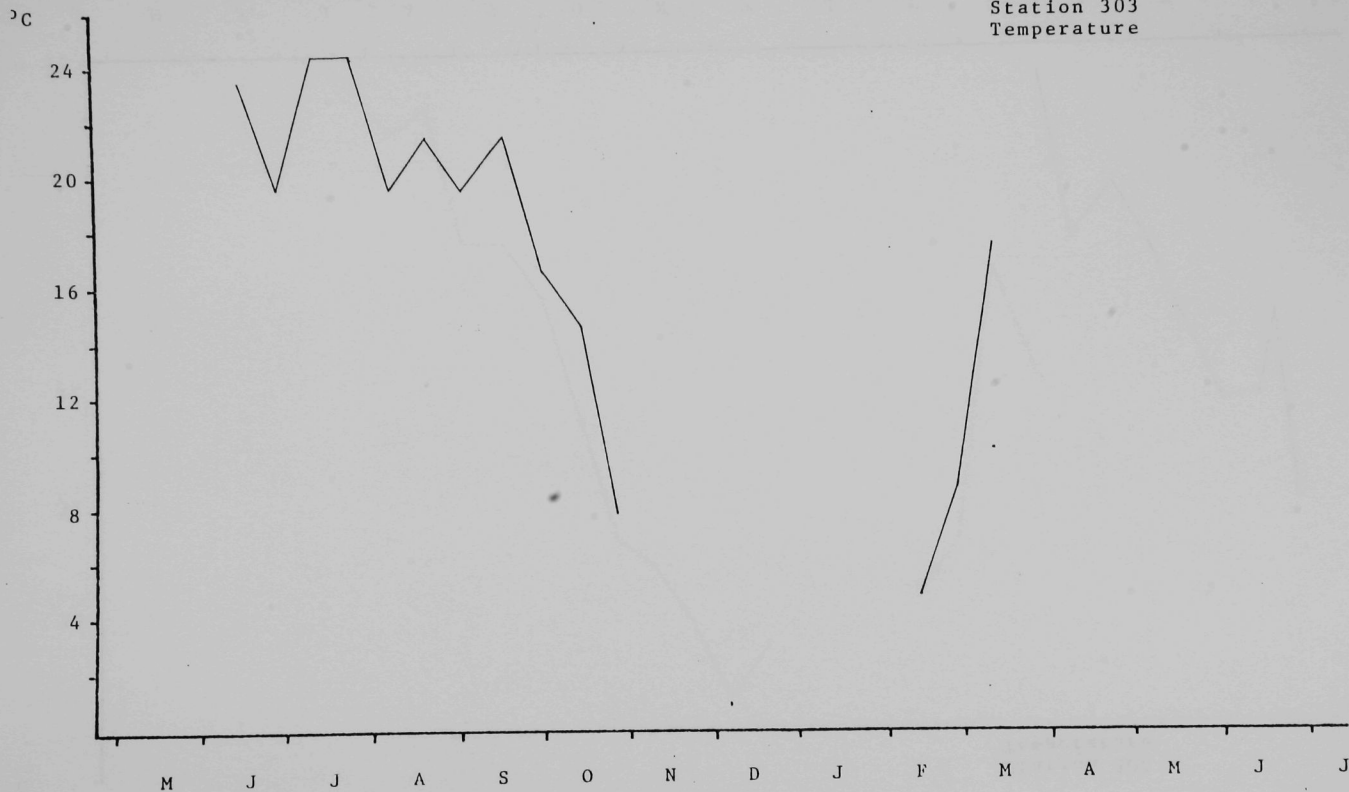
pH Lab and field



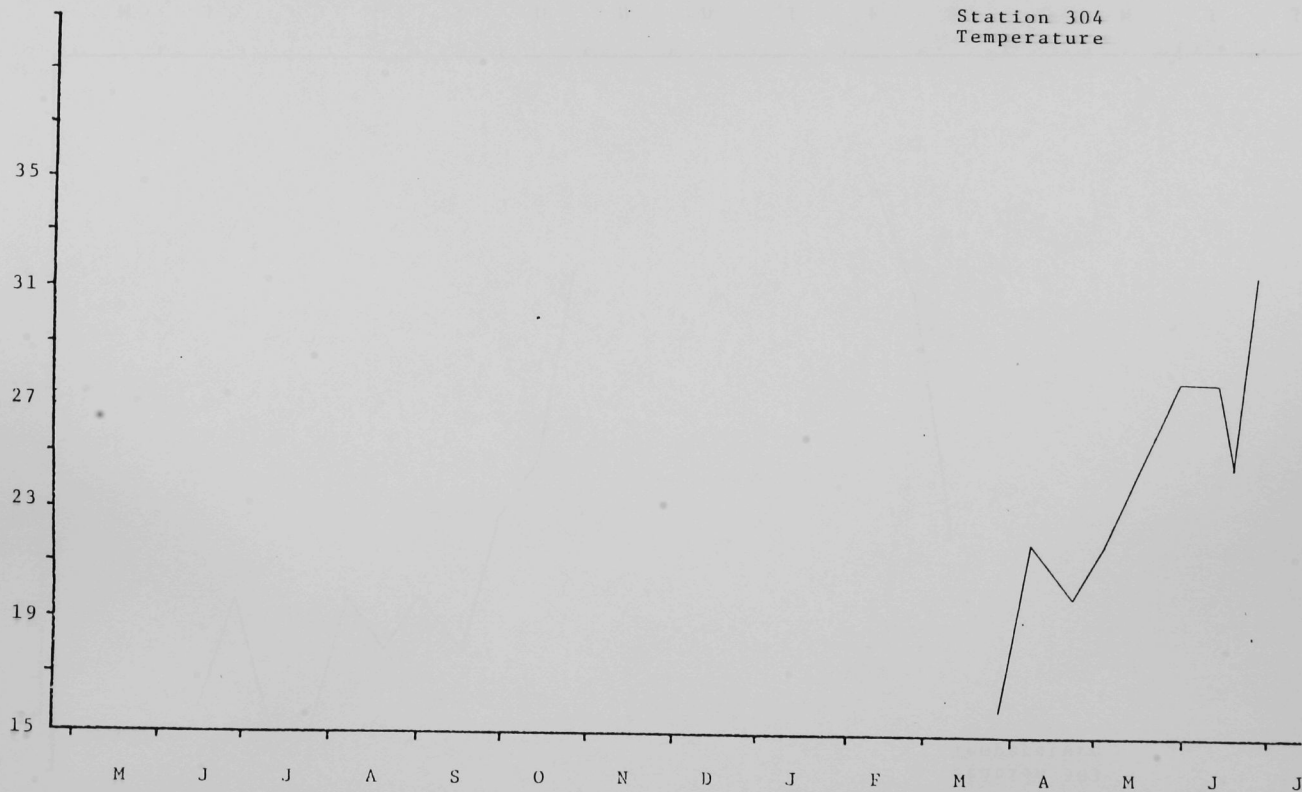


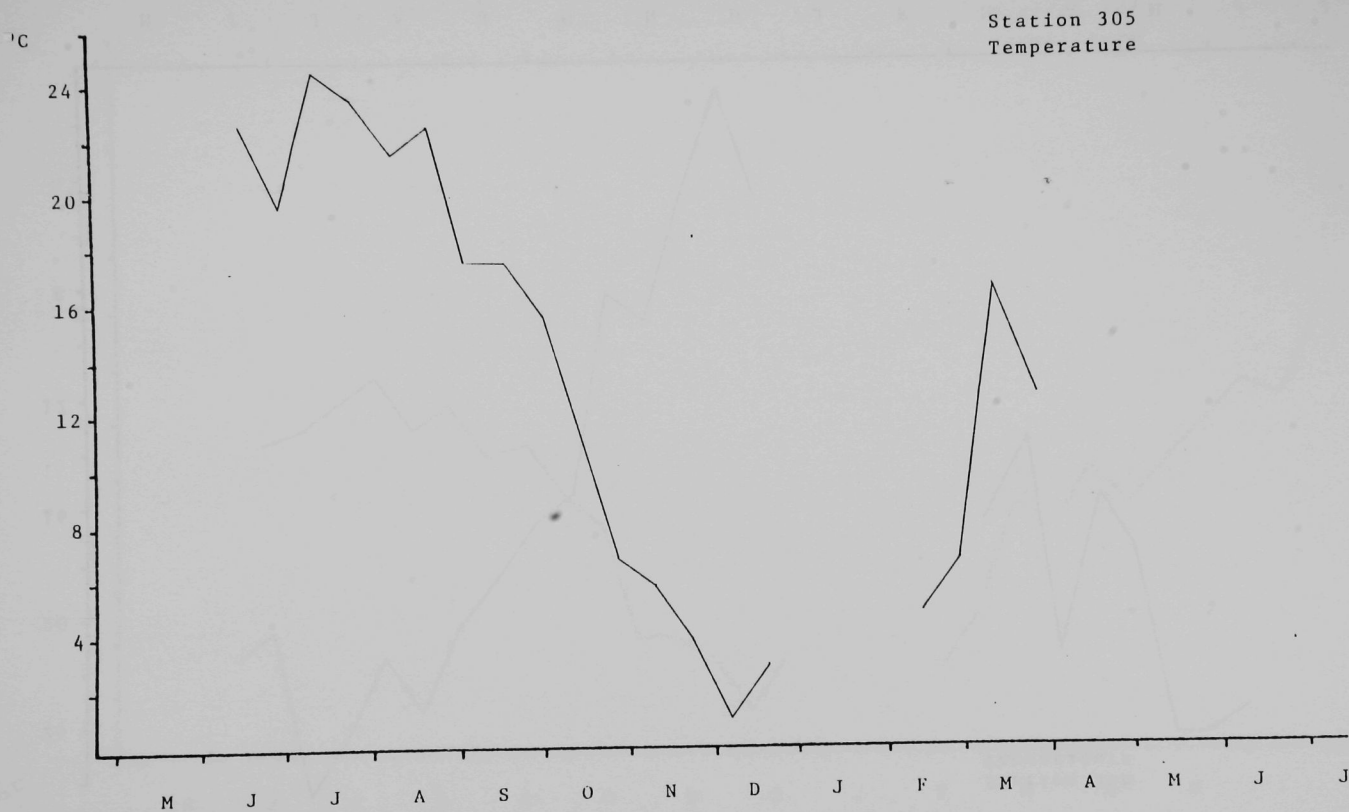


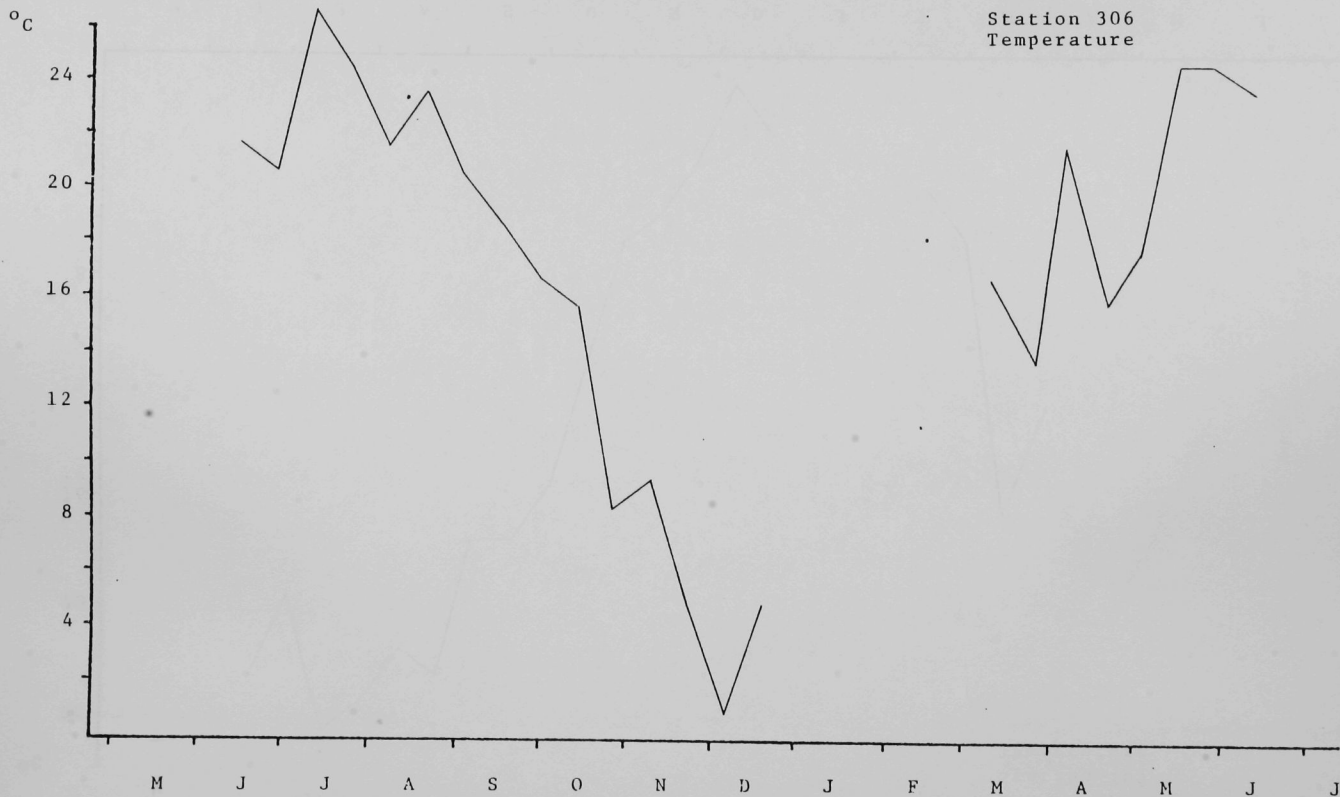




°C

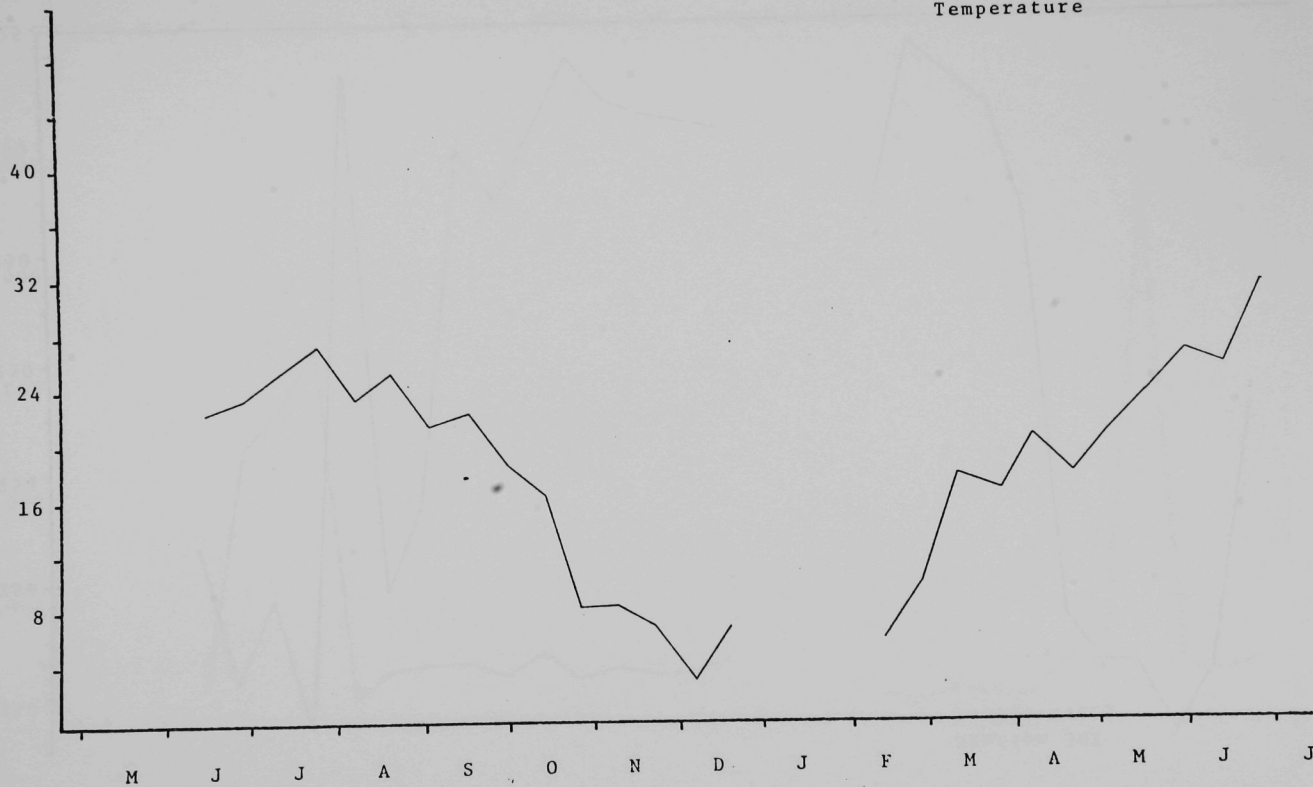




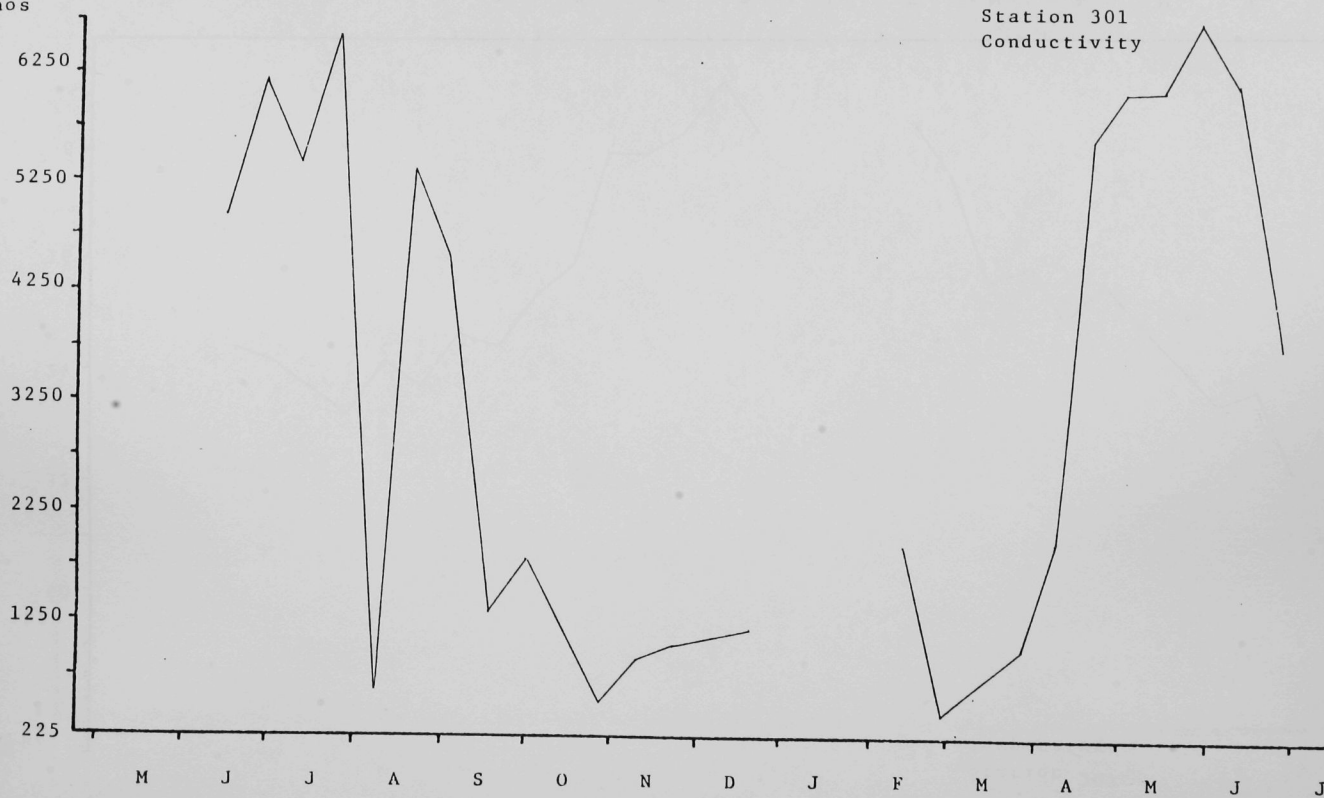


°C

Station 307
Temperature



umhos



hos

Station 302
Conductivity

10,000

8,000

6,000

4,000

2,000

M

J

J

A

S

O

N

D

J

F

M

A

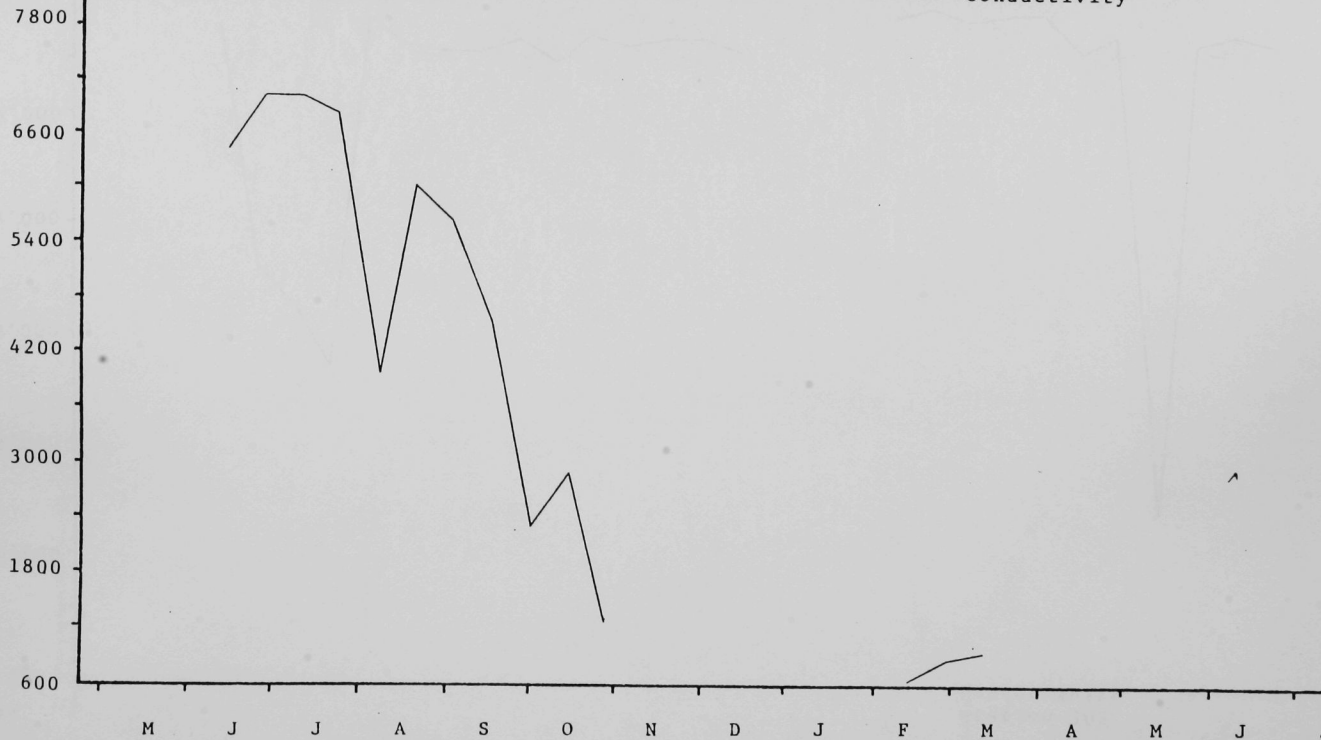
M

J

J

umhos

Station 303
Conductivity



OS

Station 304
Conductivity

5000

4200

3400

2600

1800

1000

M

J

J

A

S

O

N

D

J

F

M

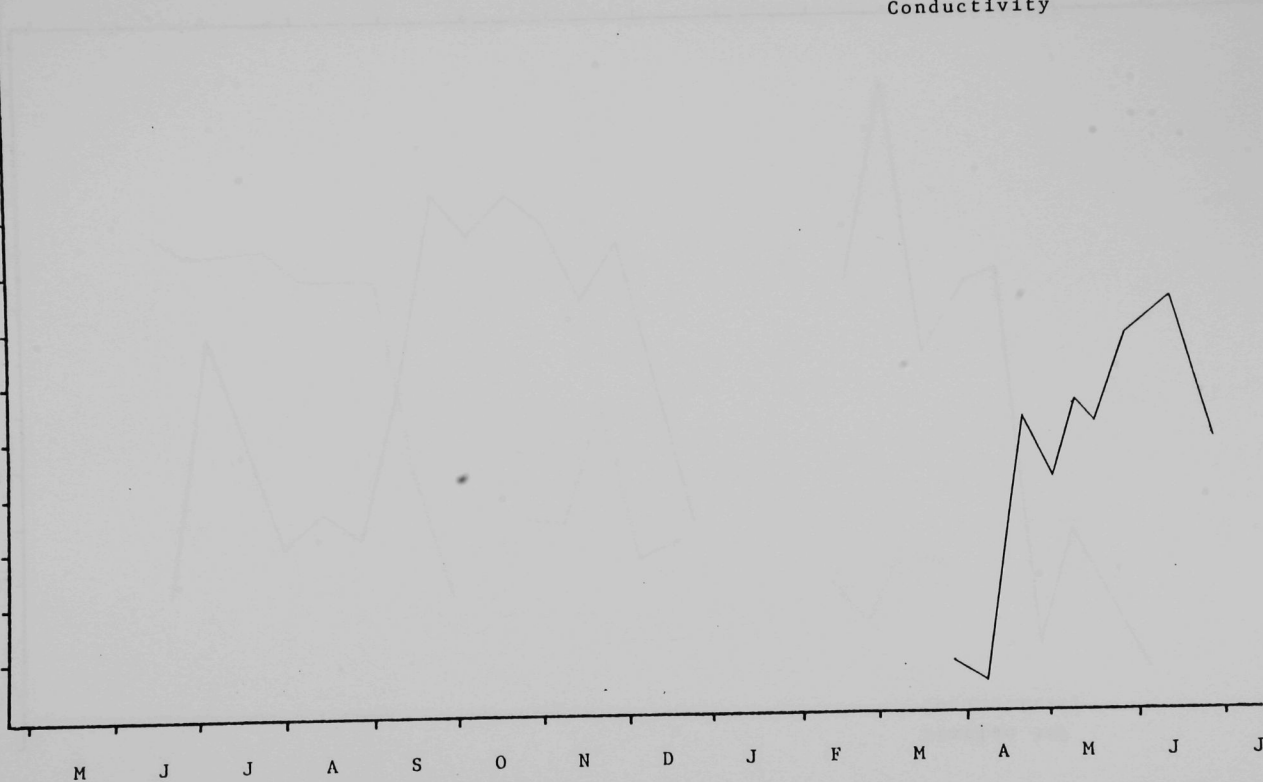
A

M

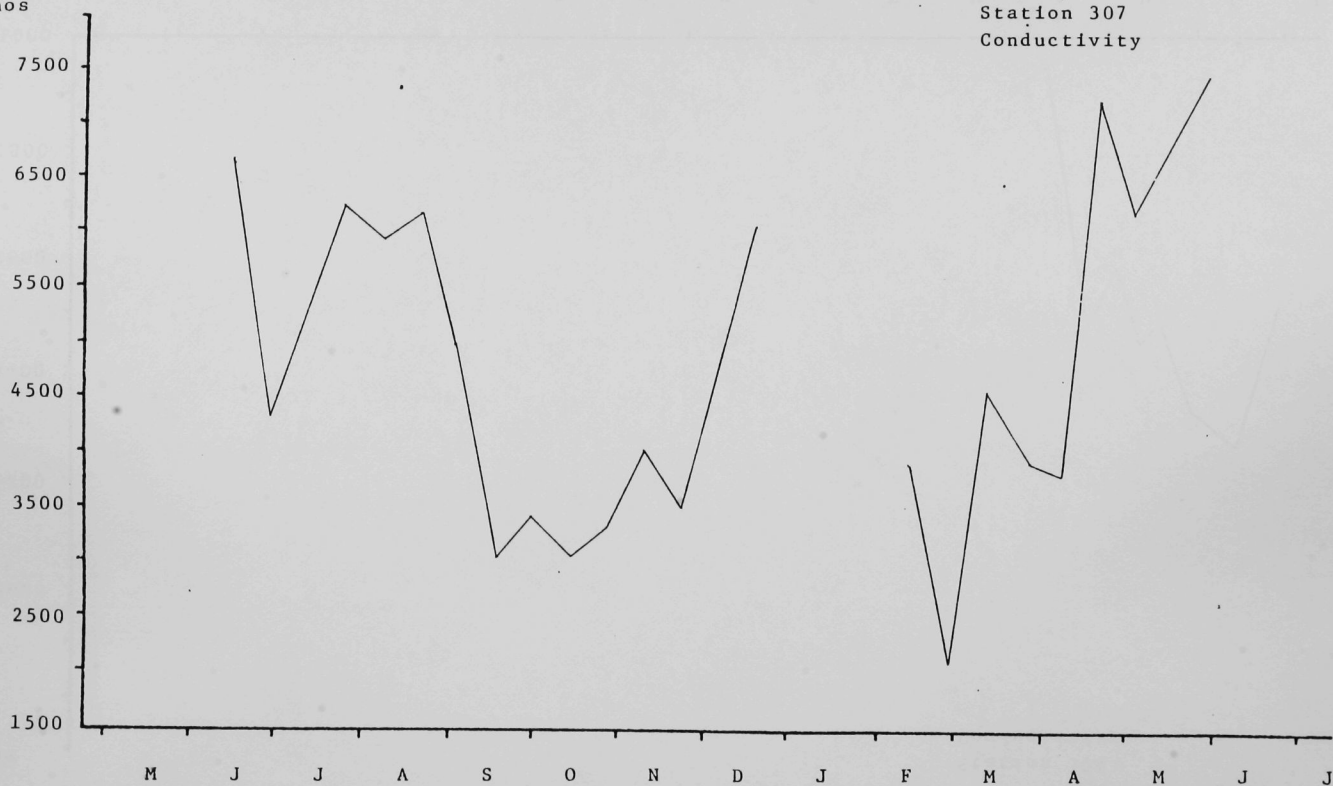
J

J

109

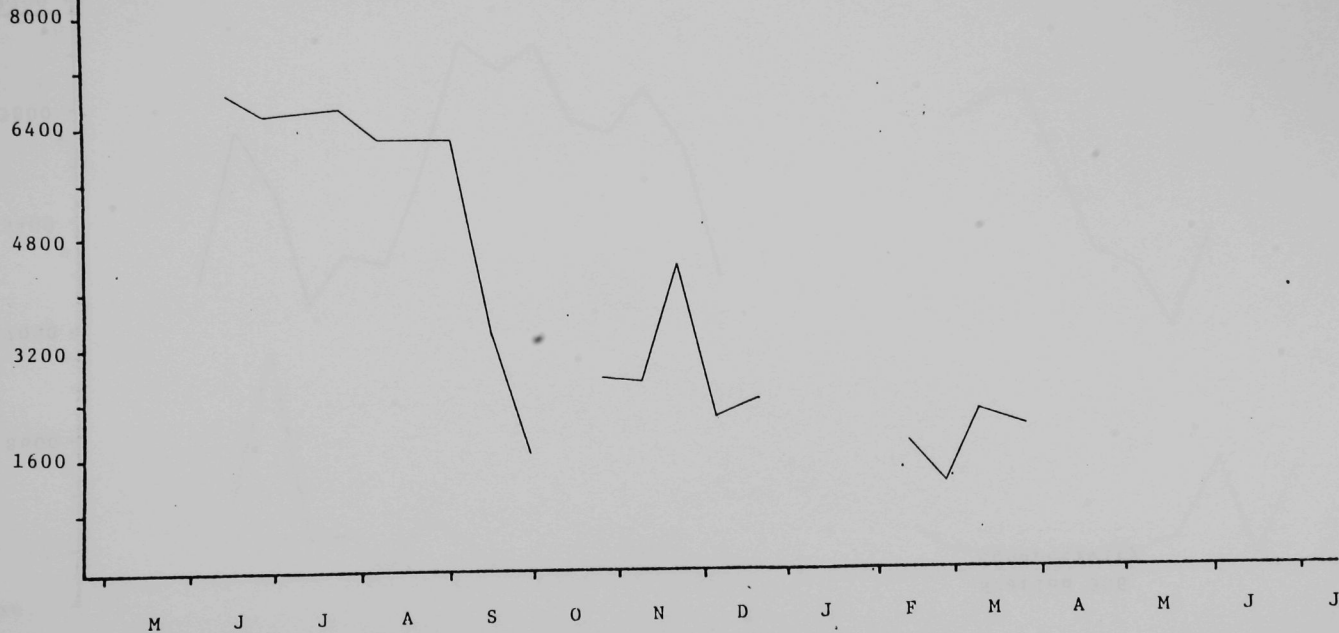


umhos



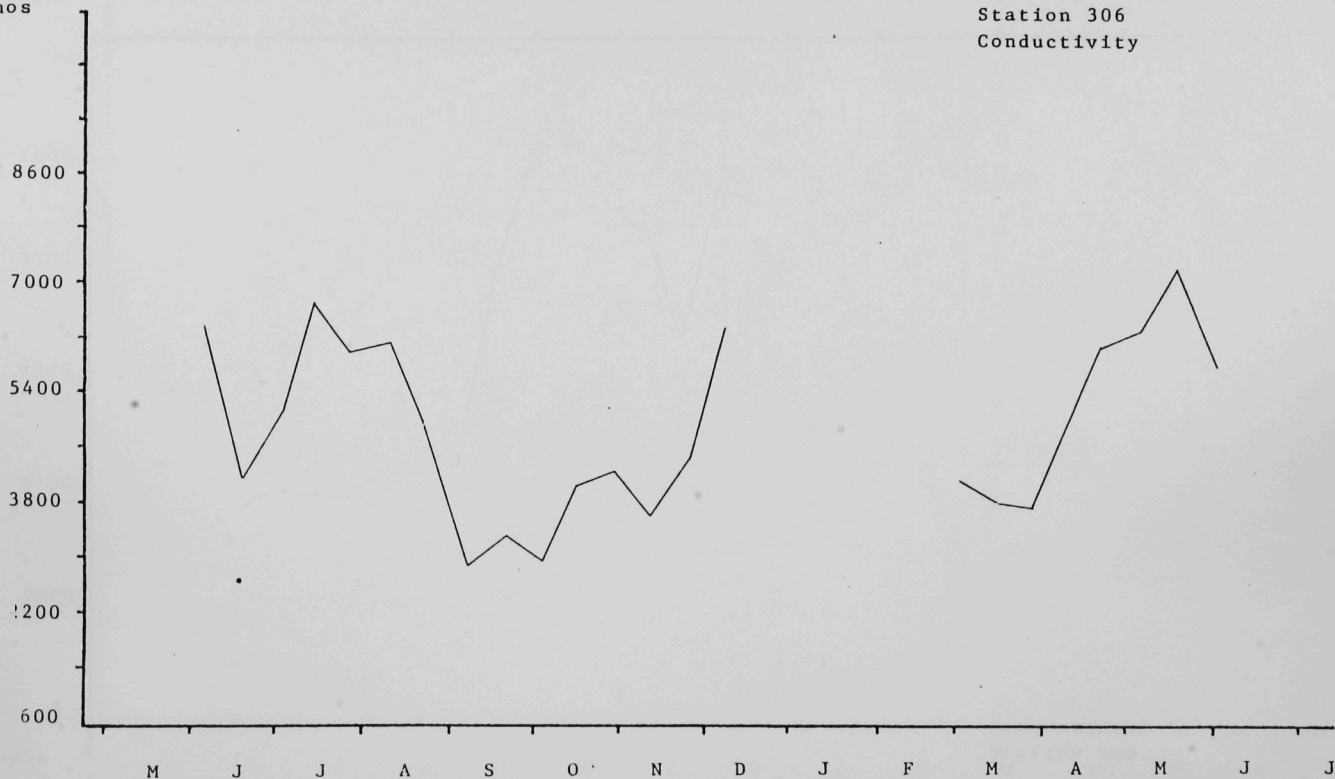
hos

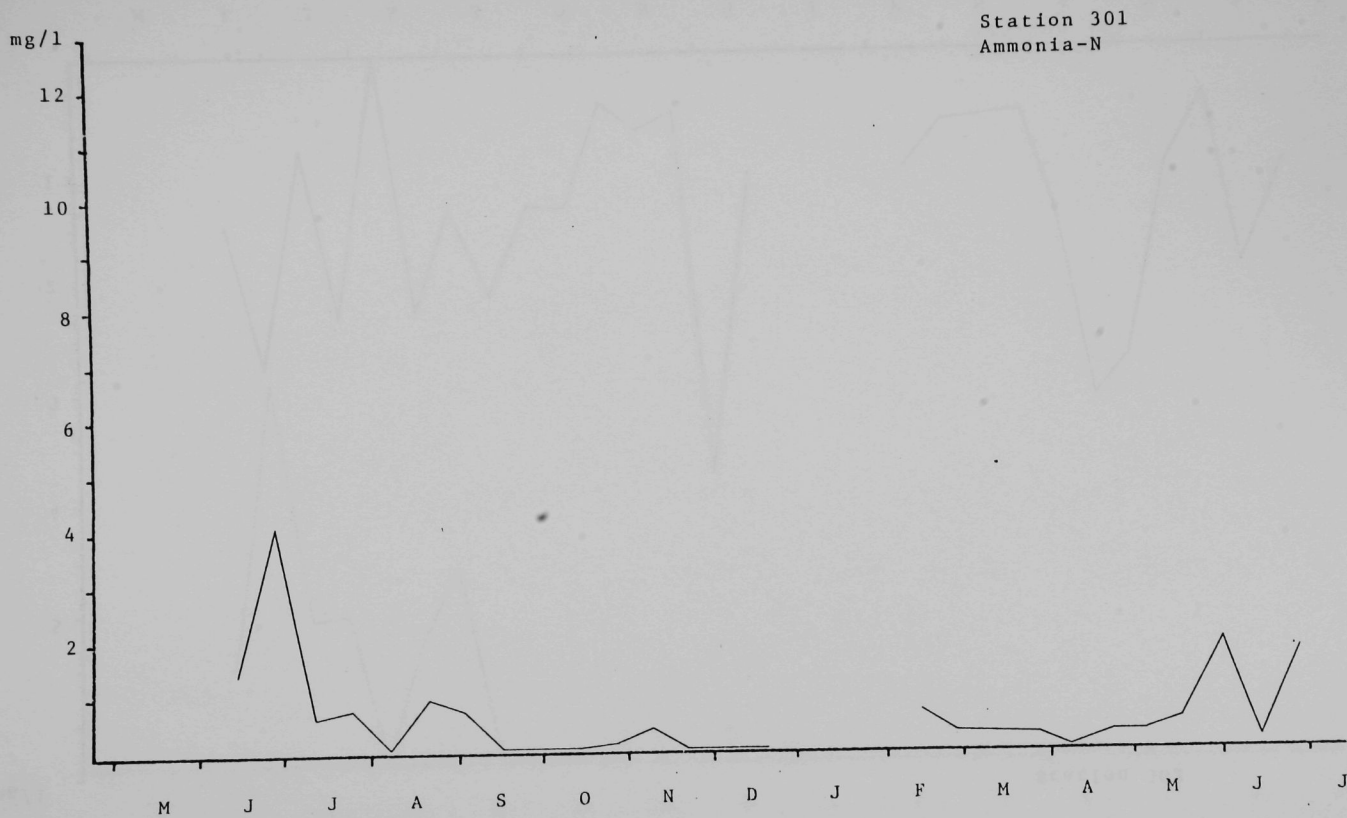
Station 305
Conductivity



umhos

Station 306
Conductivity

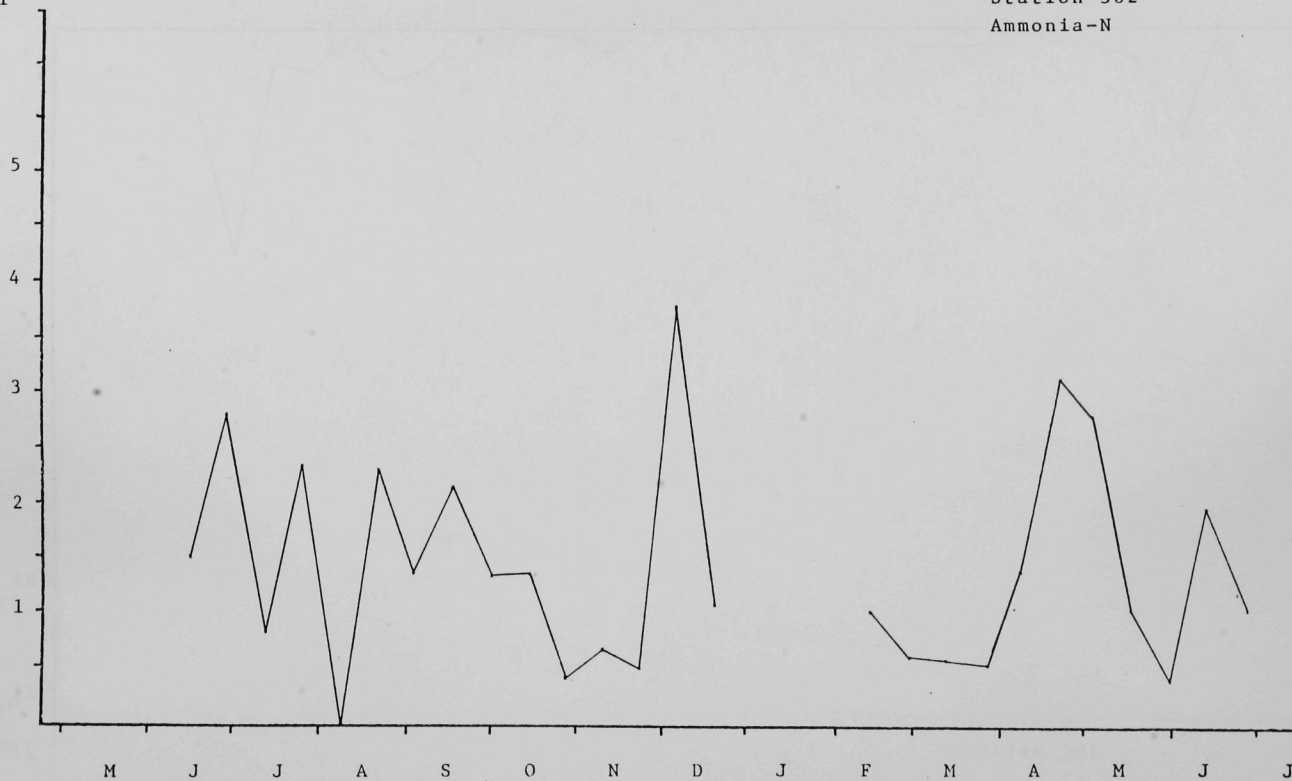




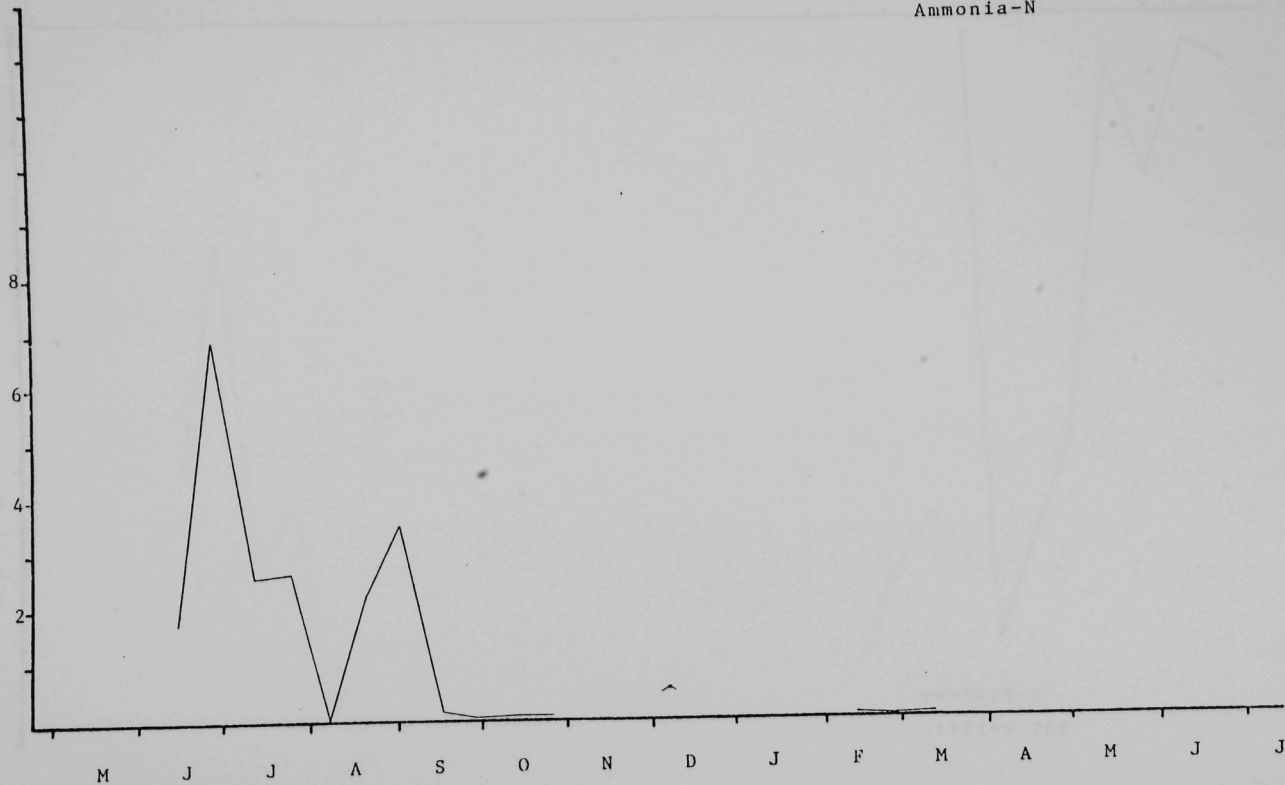
mg/l

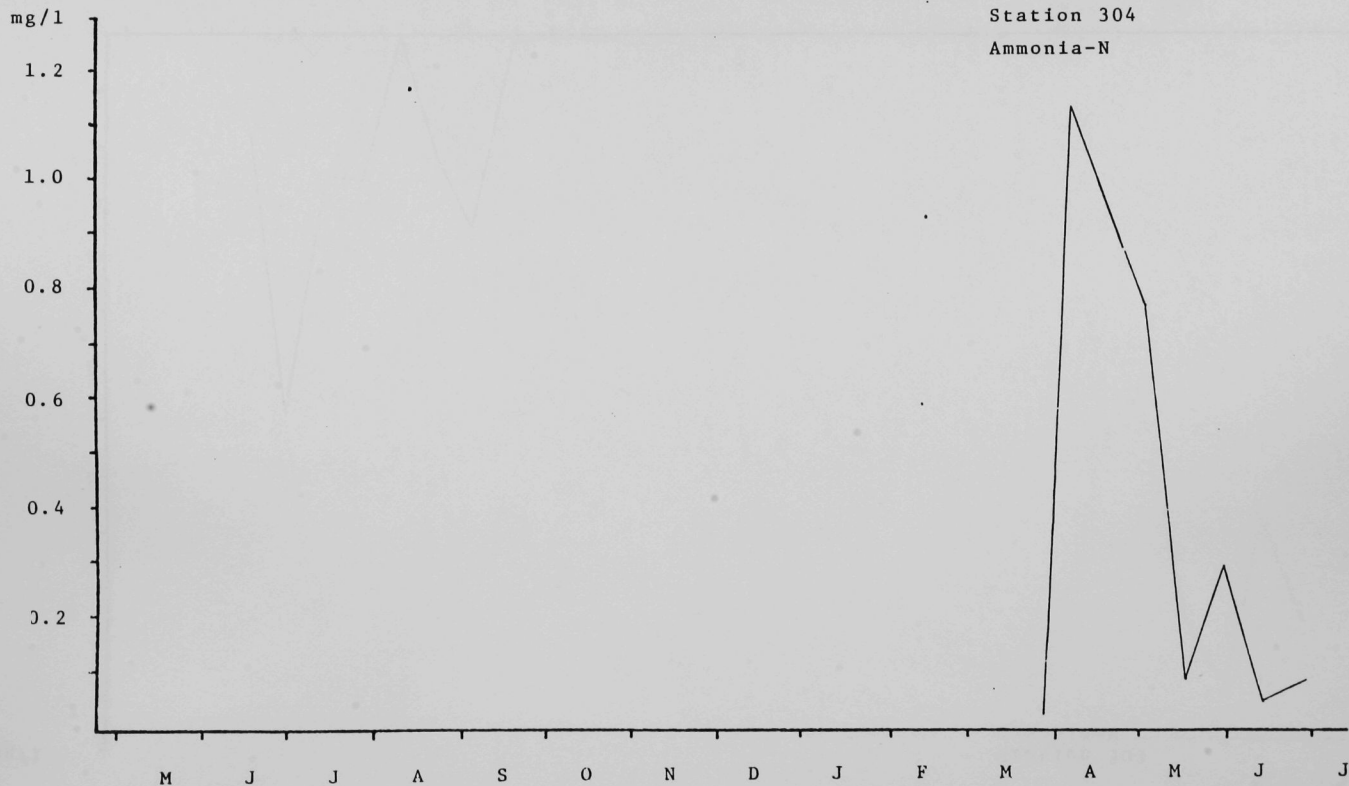
Station 302

Ammonia-N



Station 303
Ammonia-N





g/l

Station 305
Ammonia-N

3.2

2.4

1.6

0.8

M

J

J

A

S

O

N

D

J

F

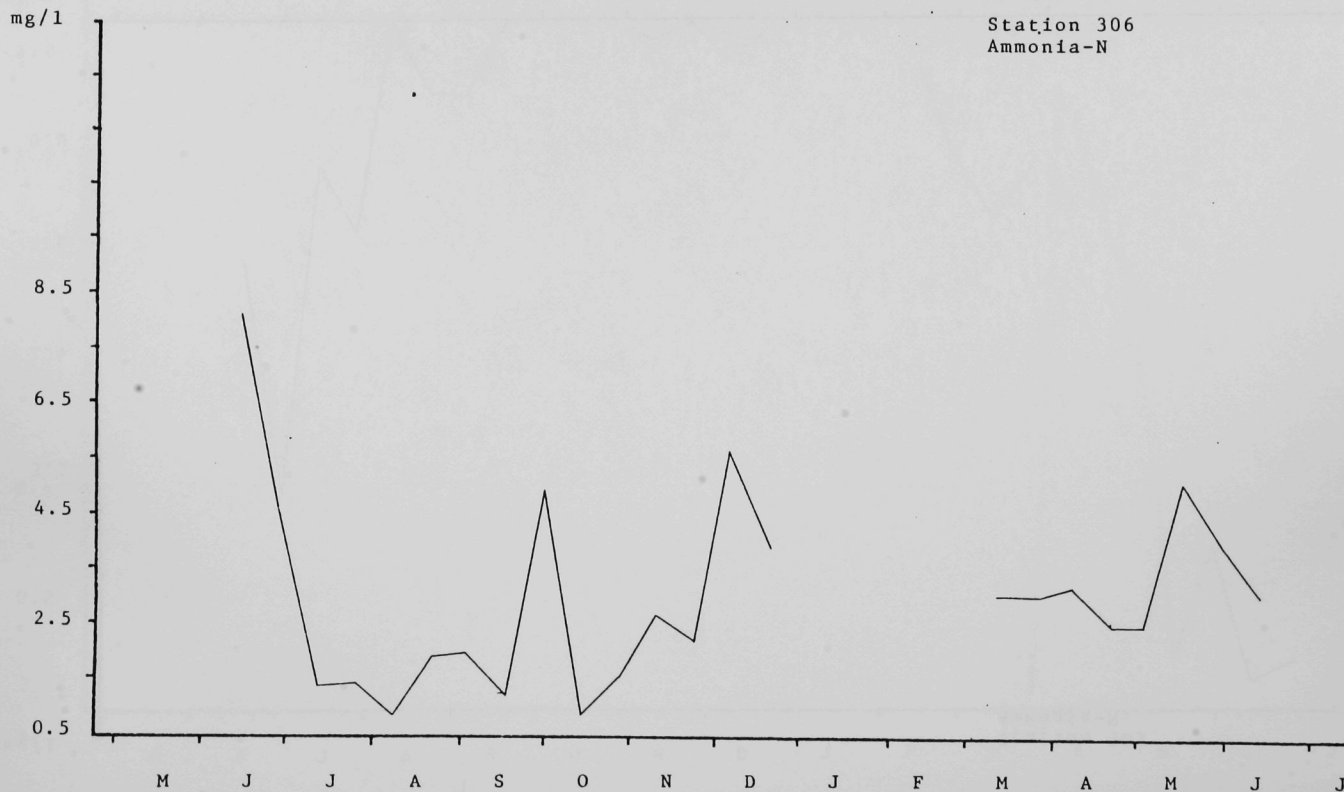
M

A

M

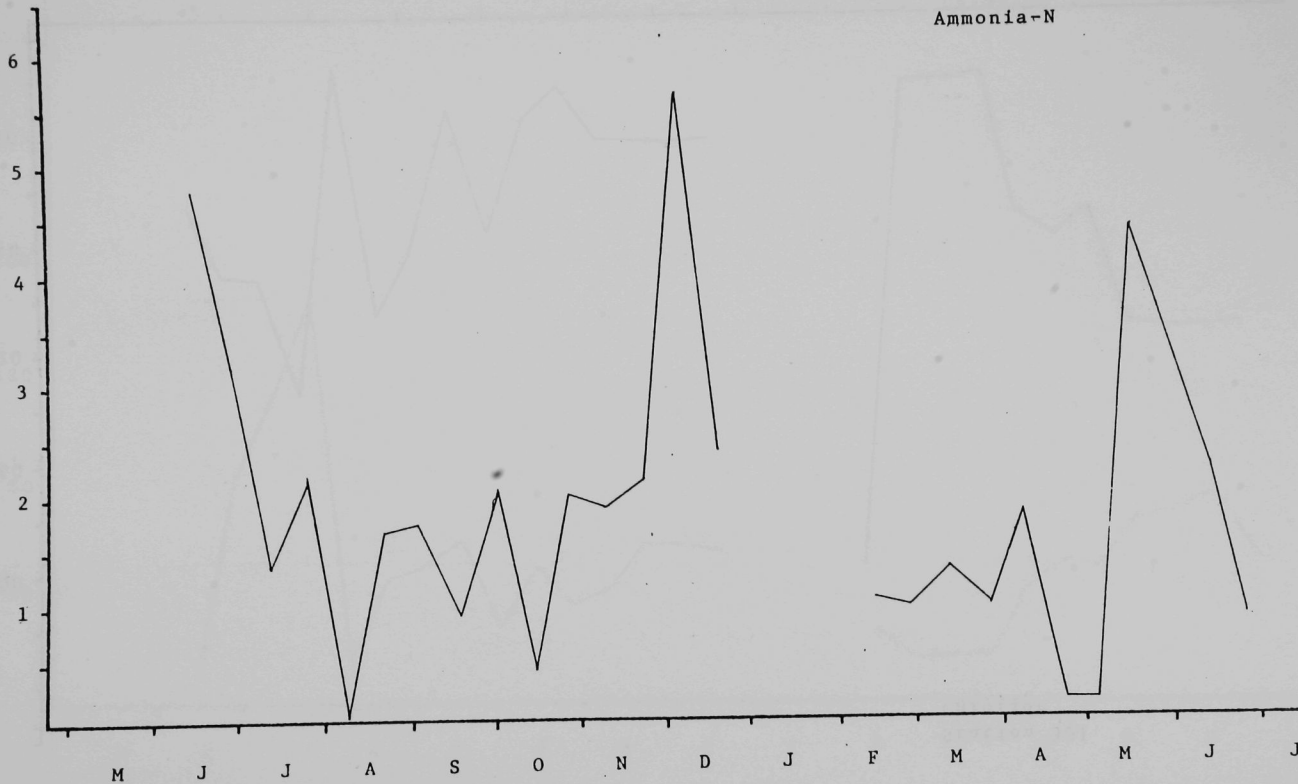
J

J



g/l

Station 307
Ammonia-N



mg/l

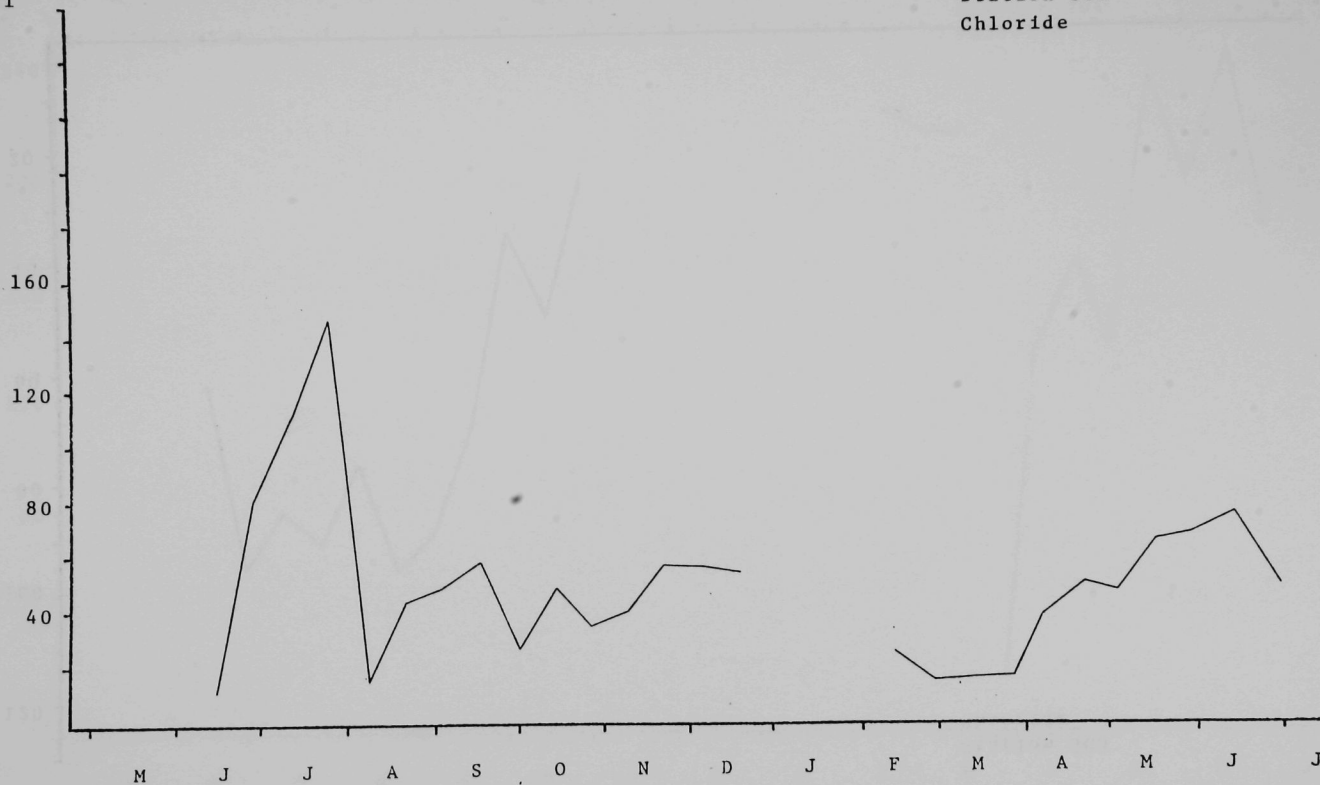
Station 301
Chloride



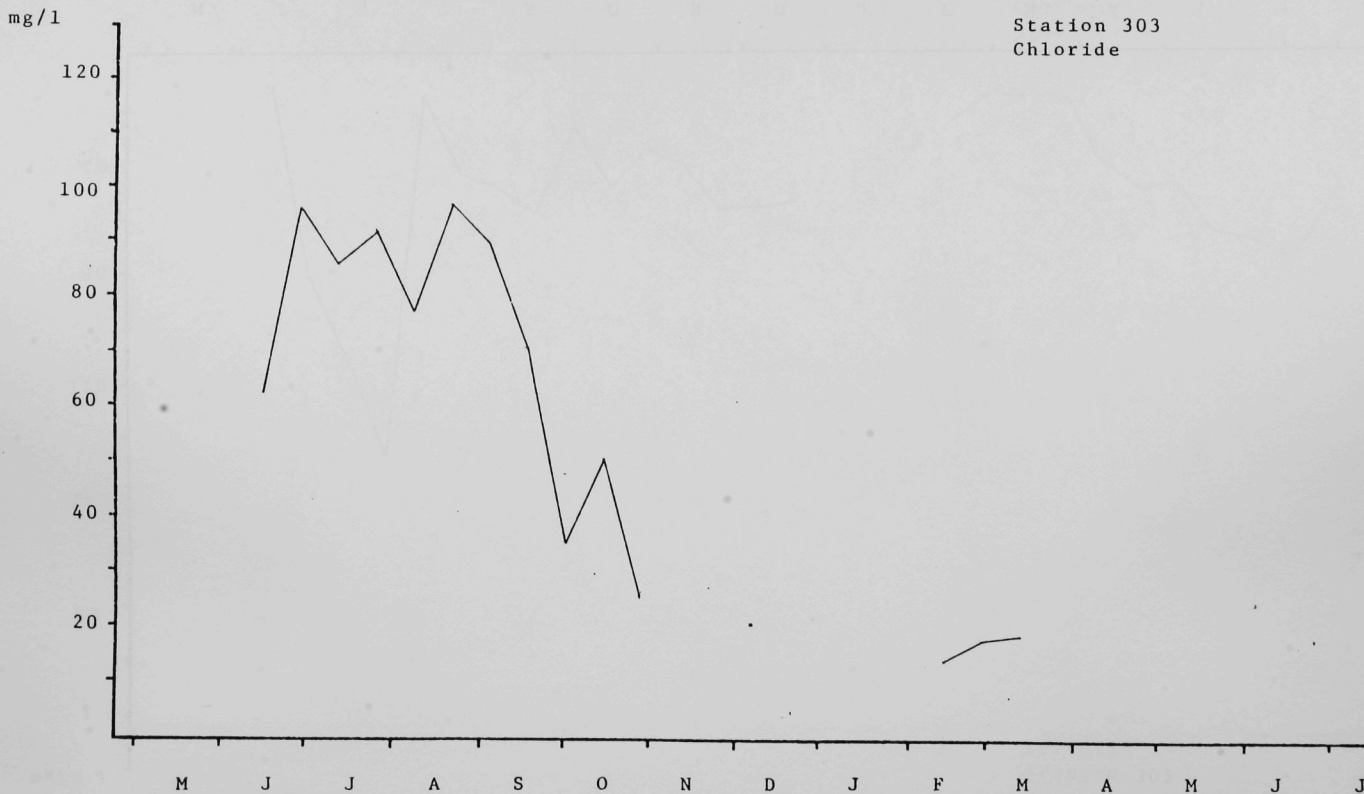
120

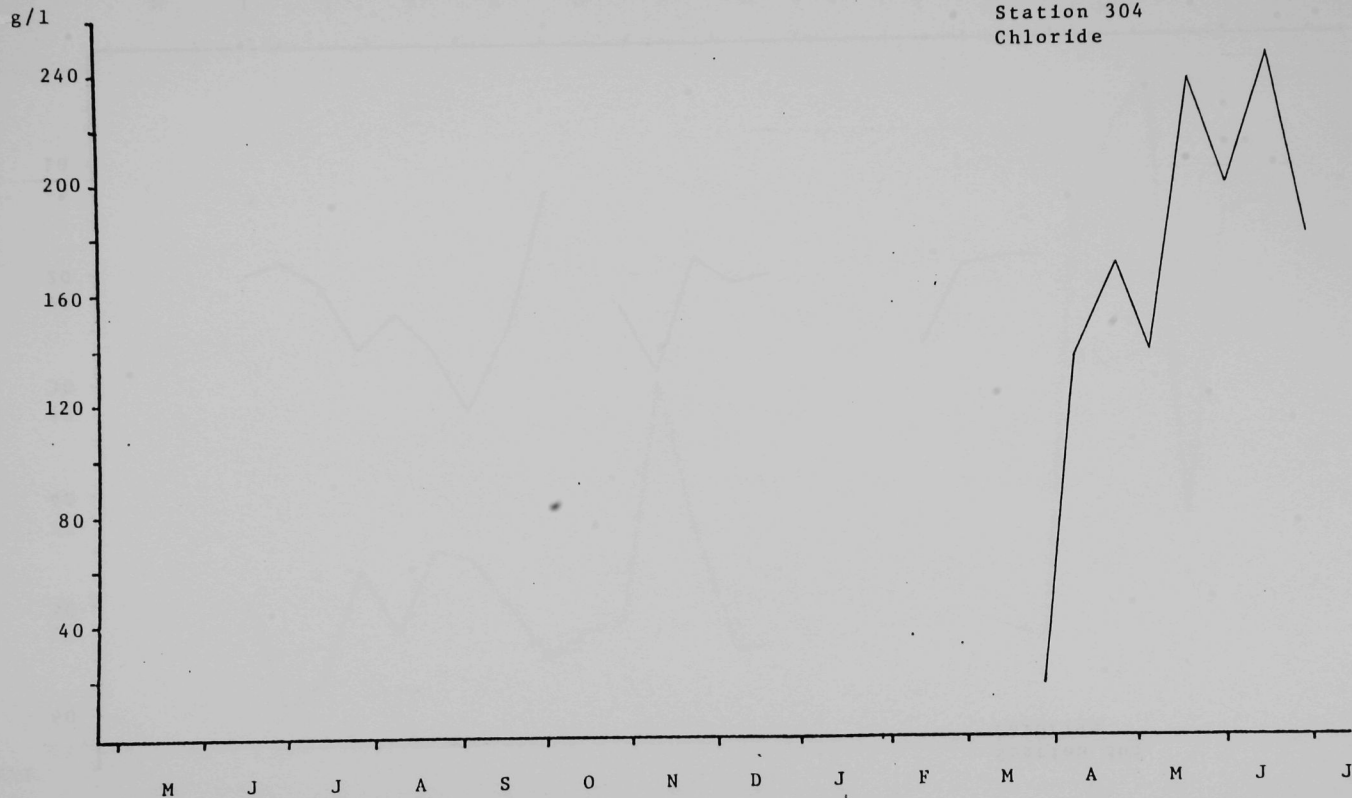
g/l

Station 302
Chloride

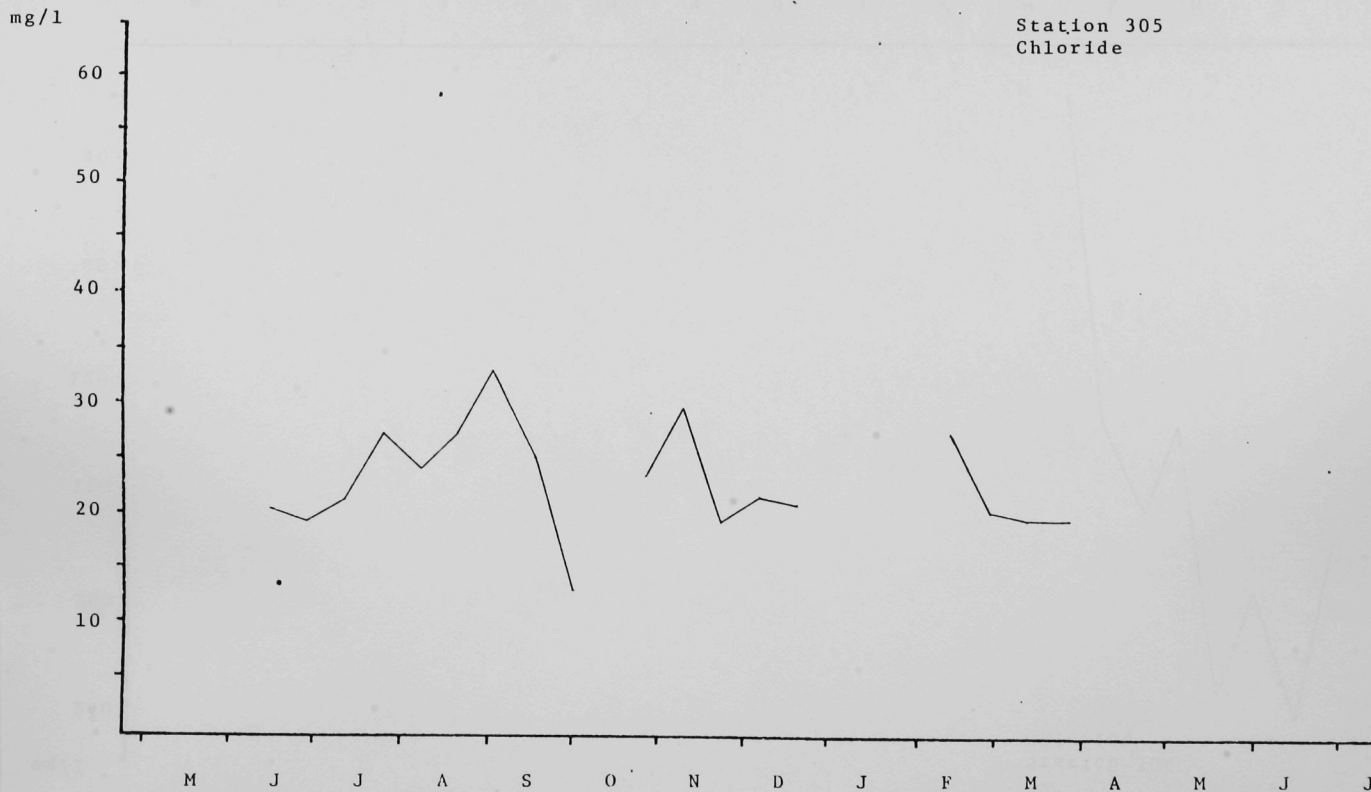


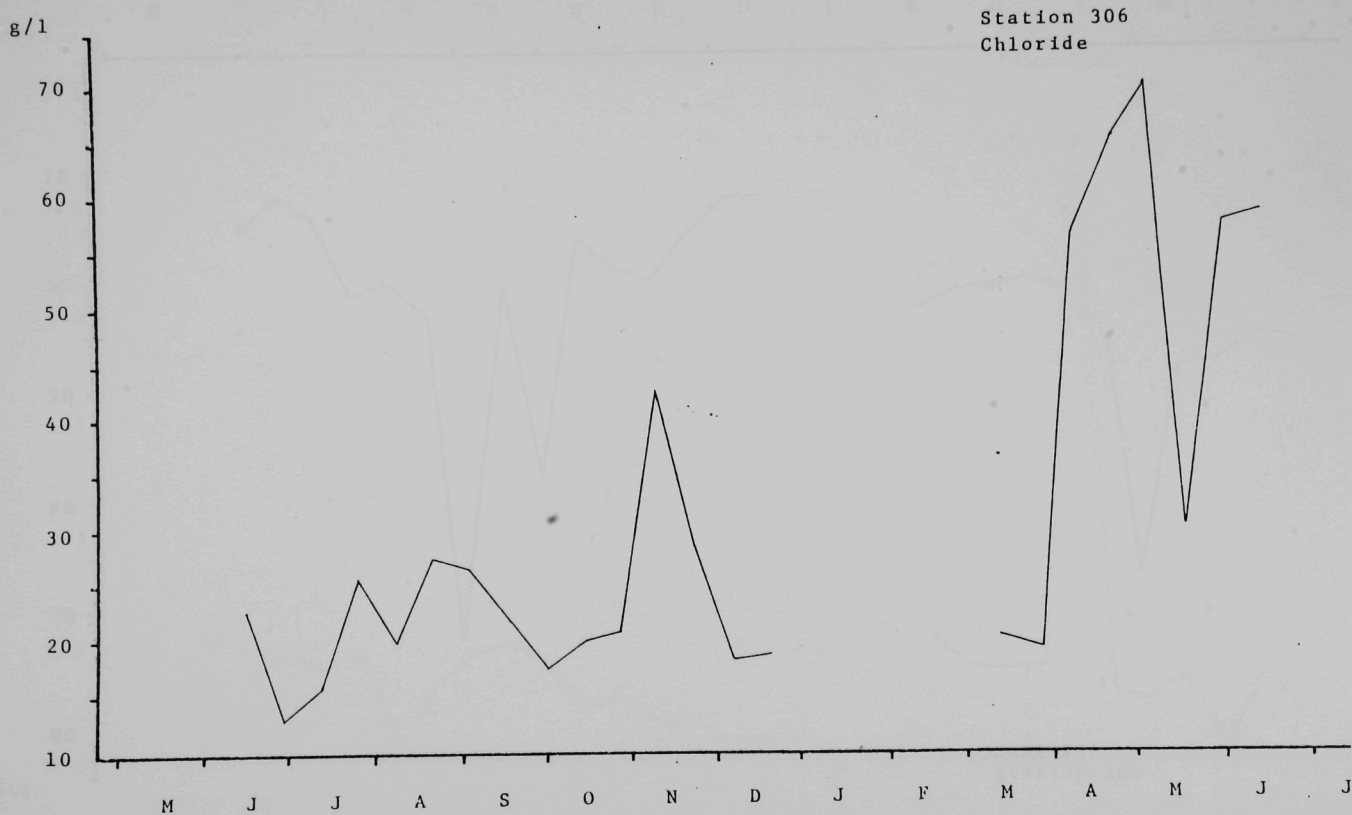
Station 303
Chloride





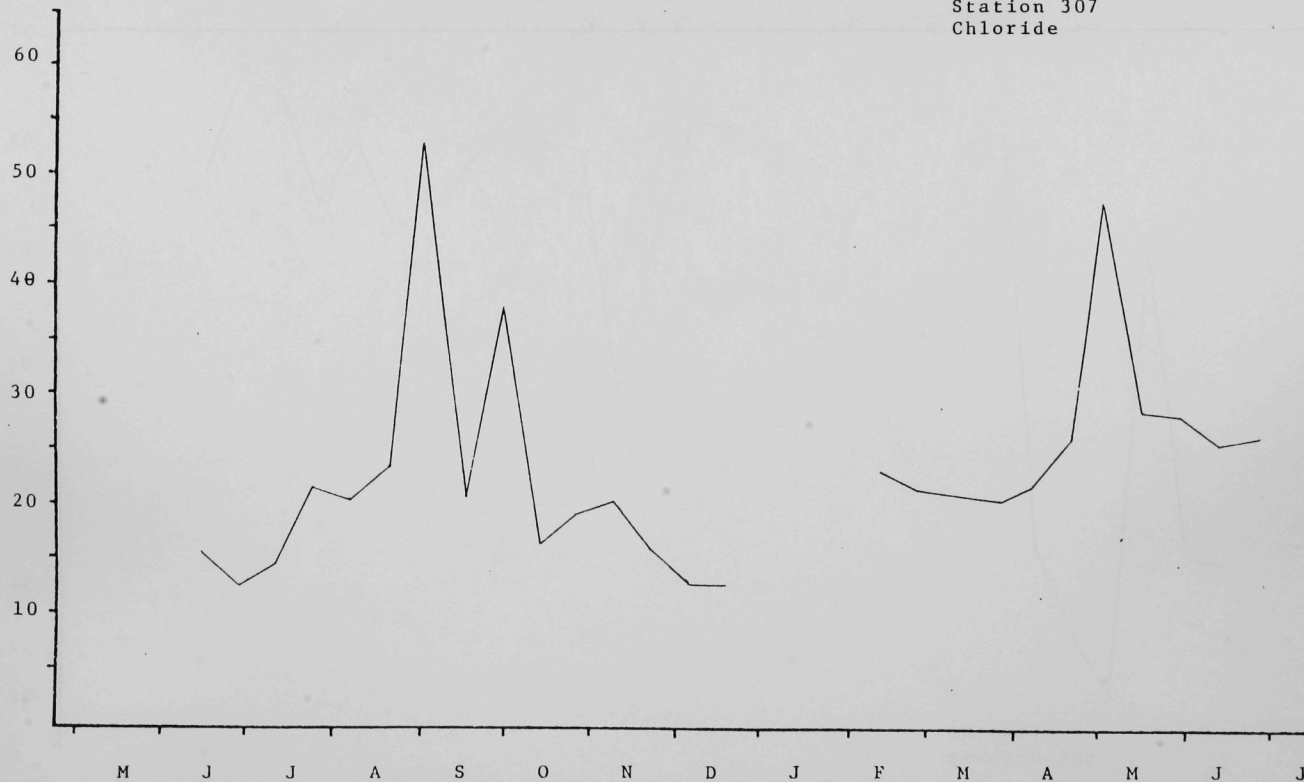
Station 305
Chloride

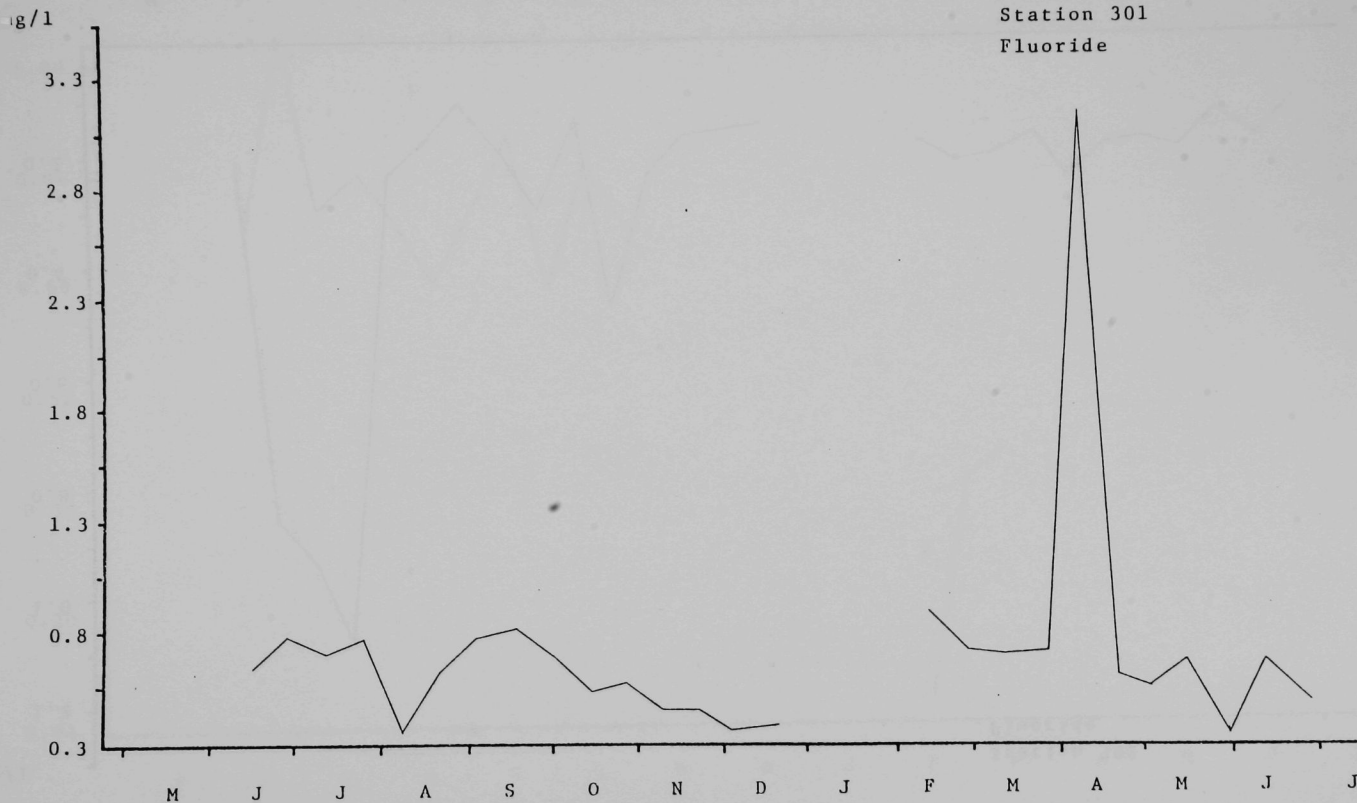




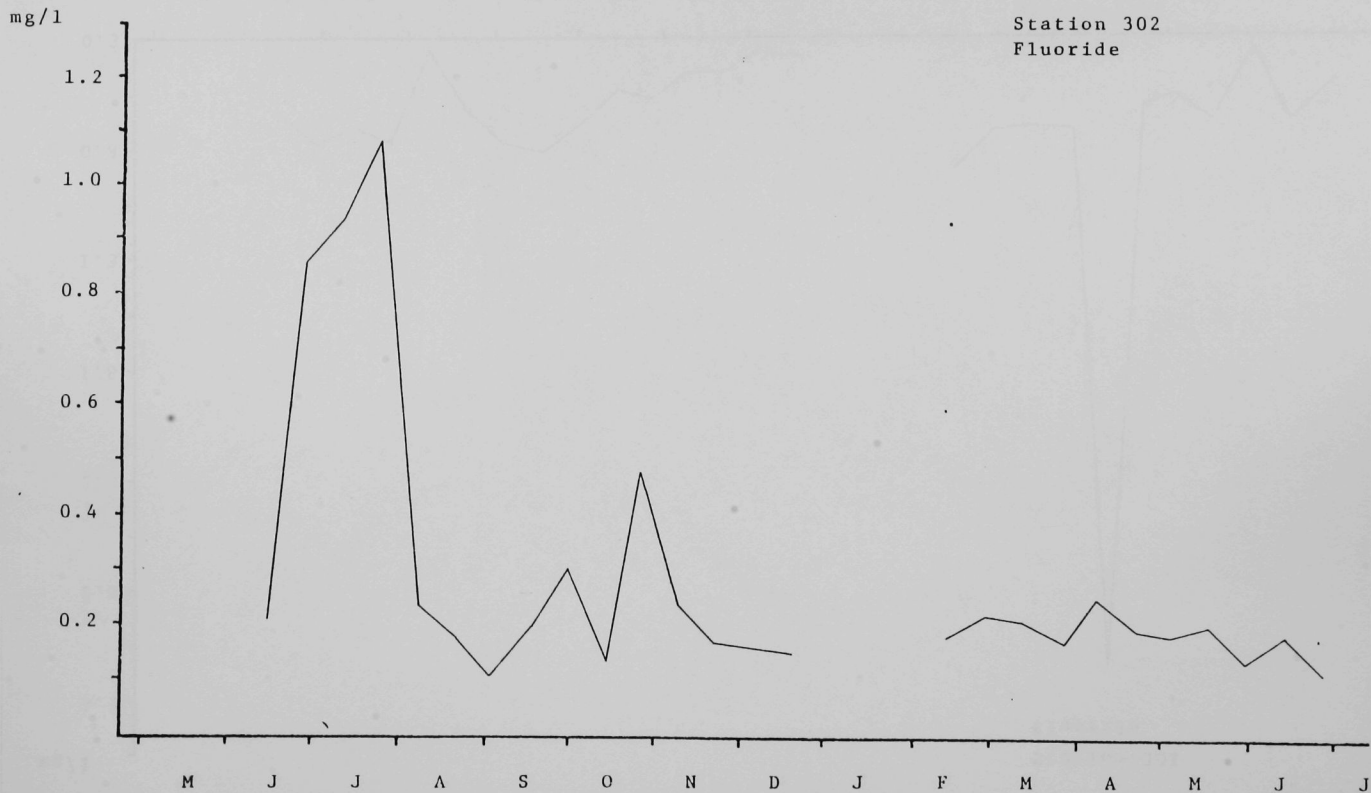
Station 307
Chloride

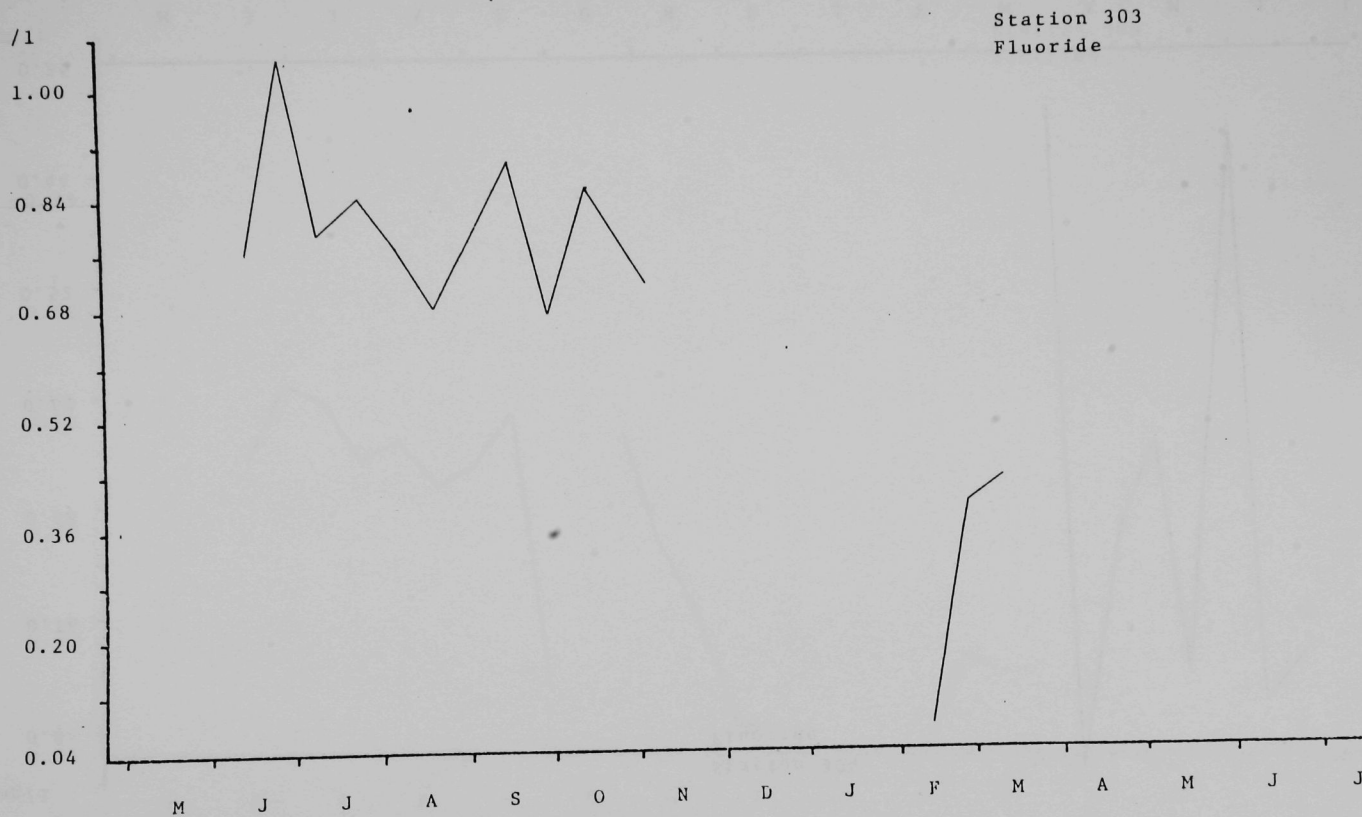
mg/l





Station 302
Fluoride





mg / l

0.84

0.76

0.68

0.60

0.52

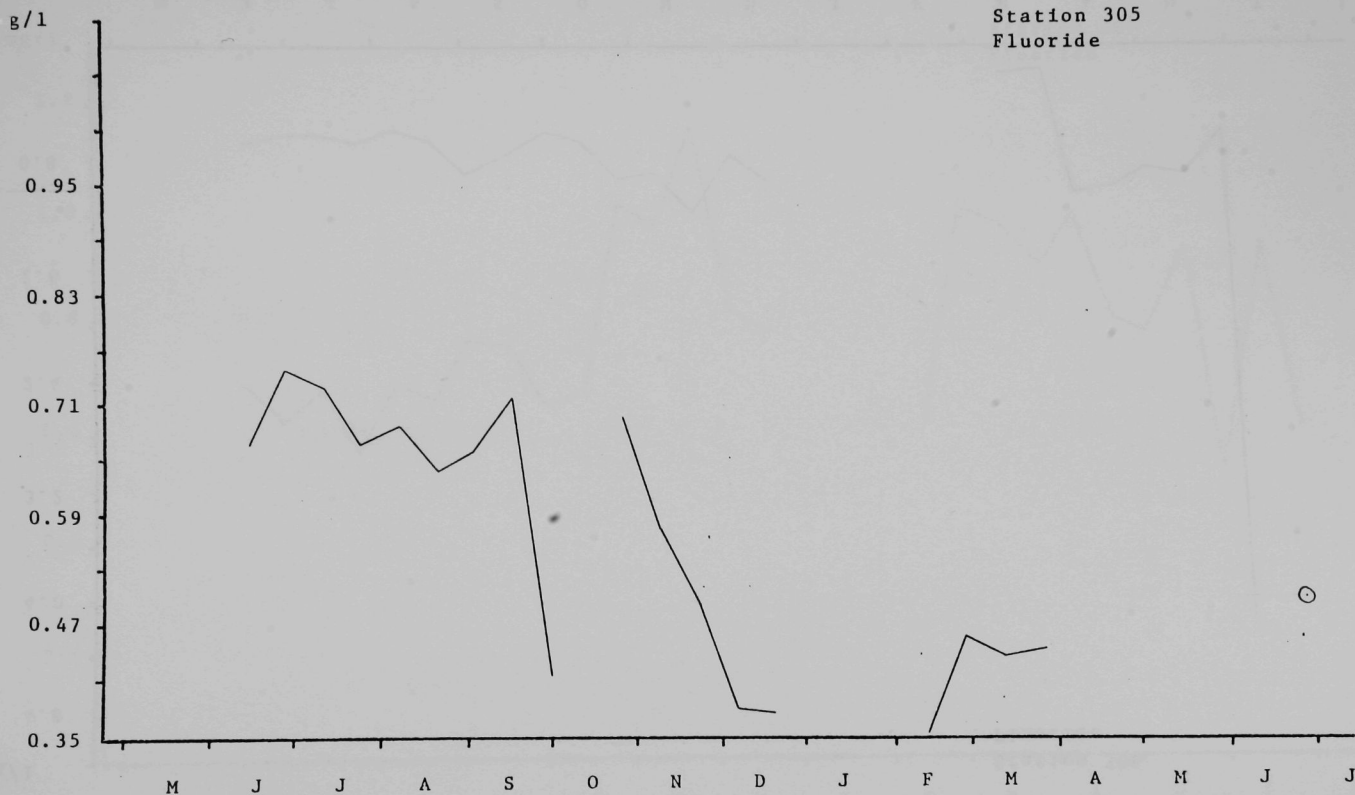
0.44

0.36

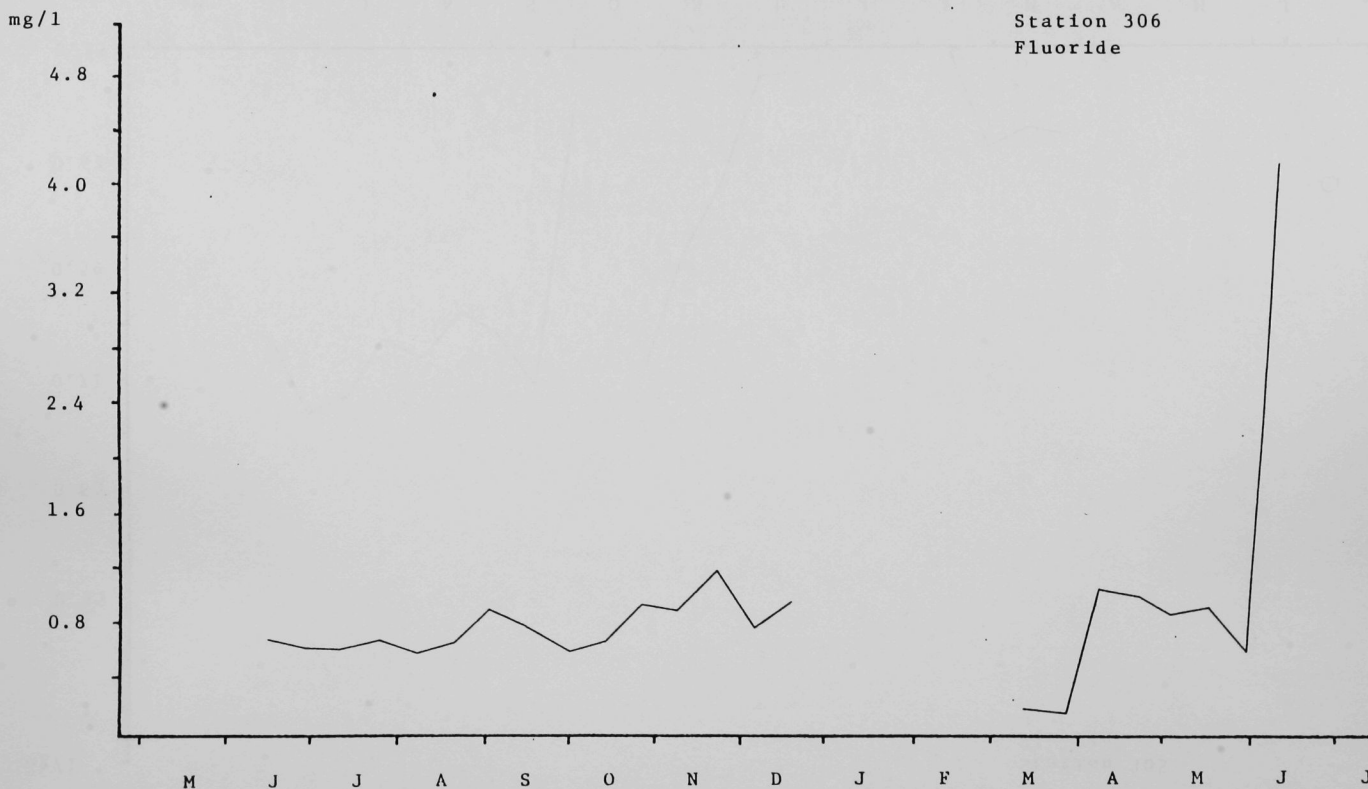
Station 304

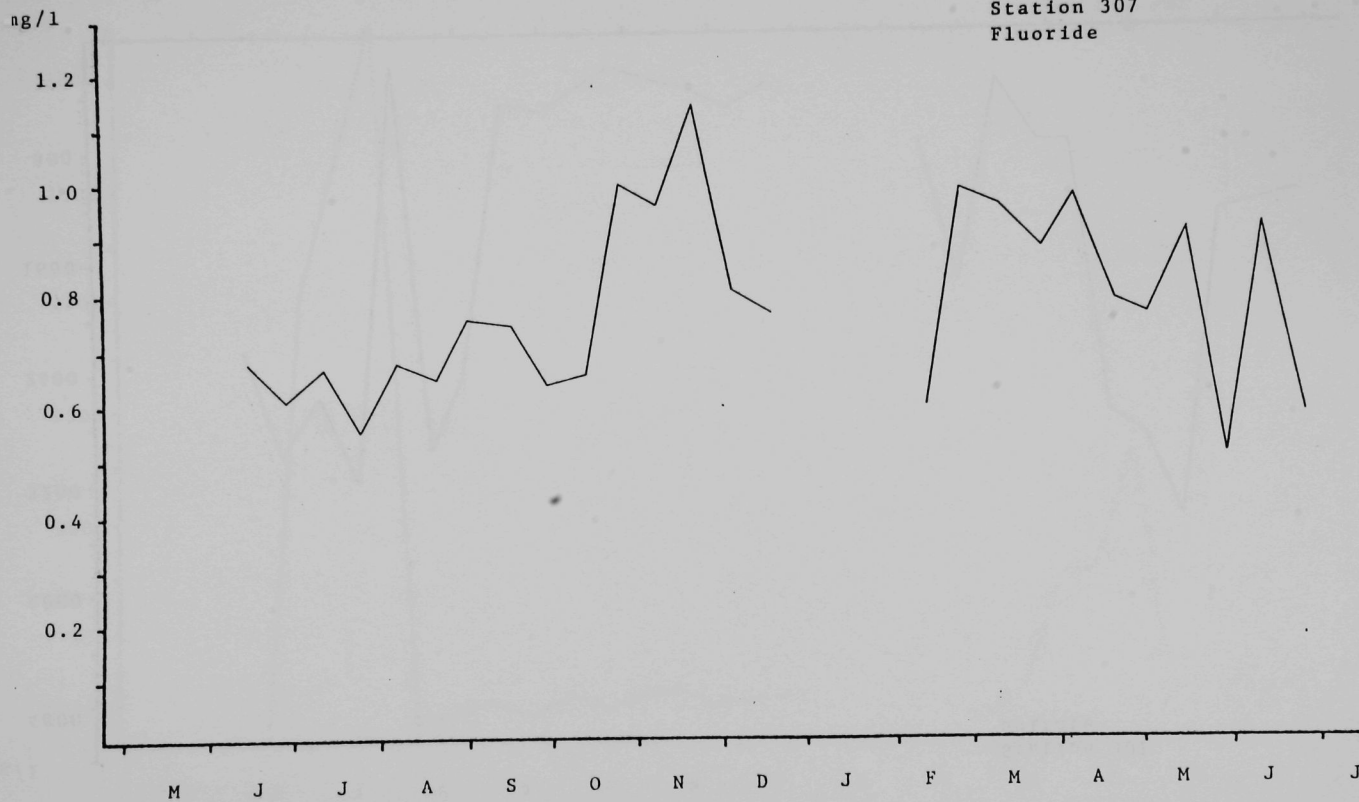
Fluoride

130



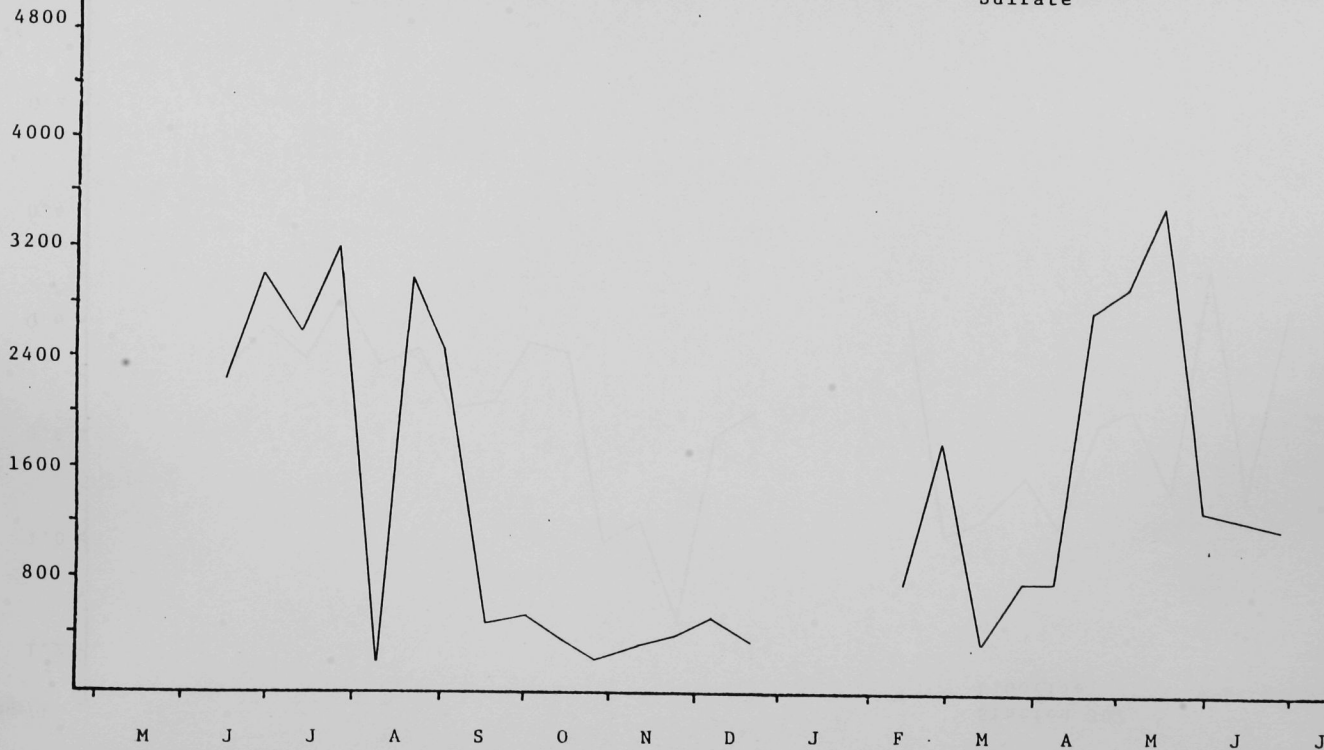
Station 306
Fluoride



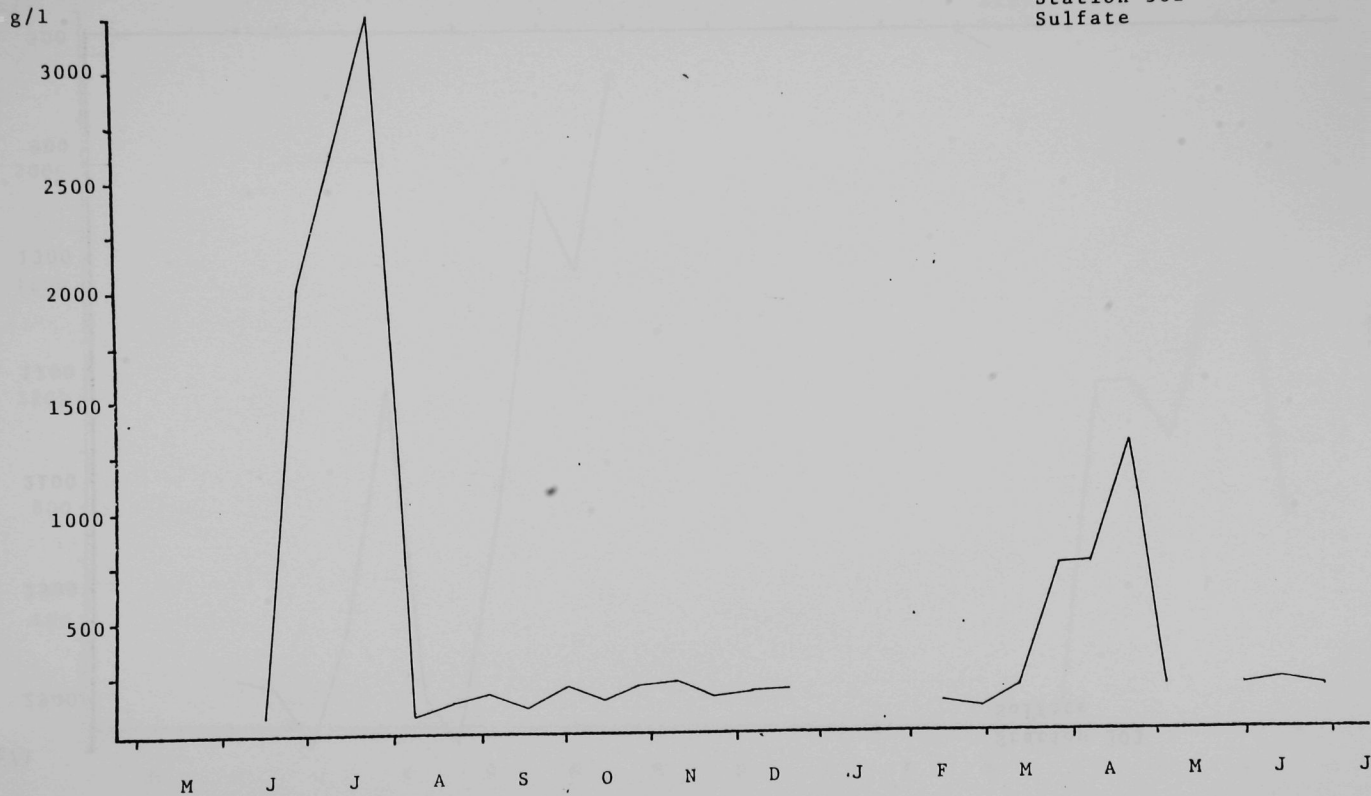


mg/l

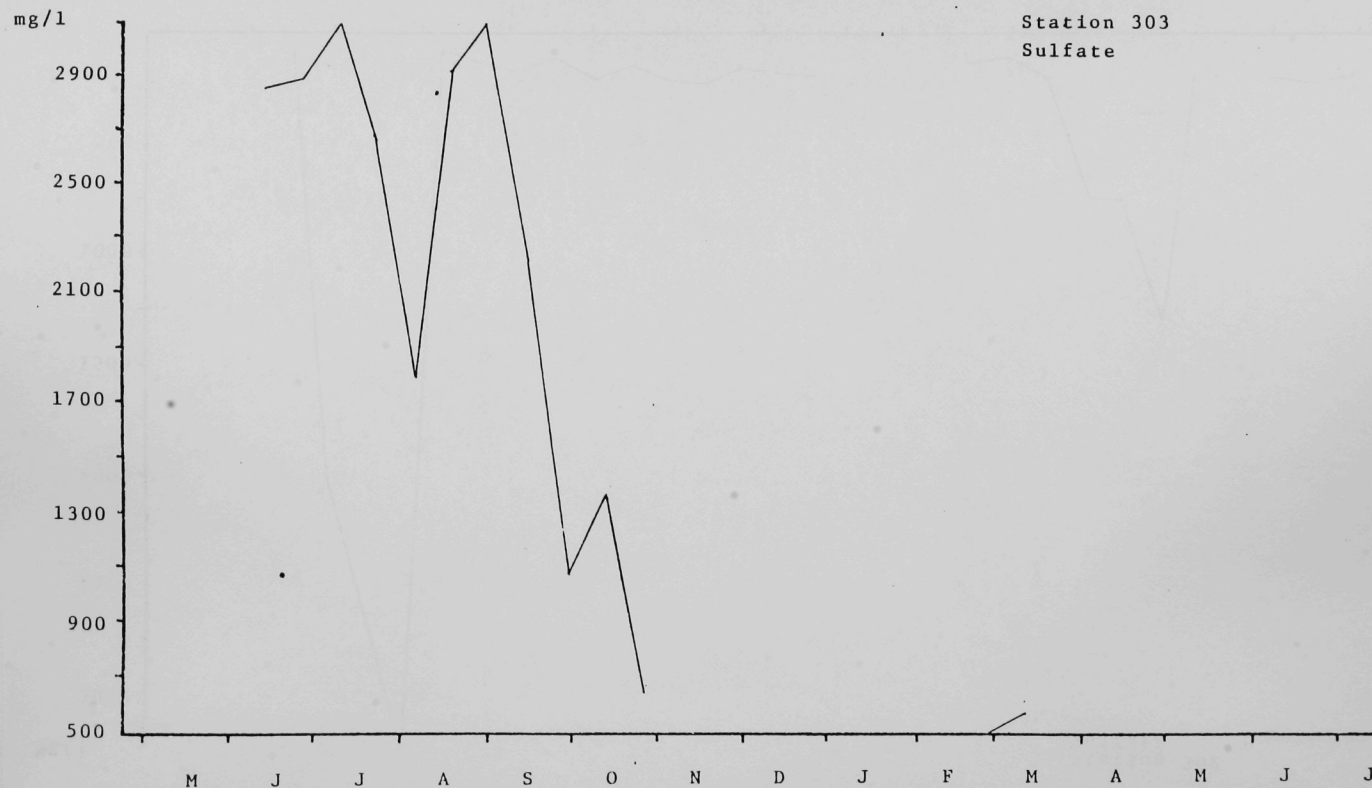
Station 301
Sulfate

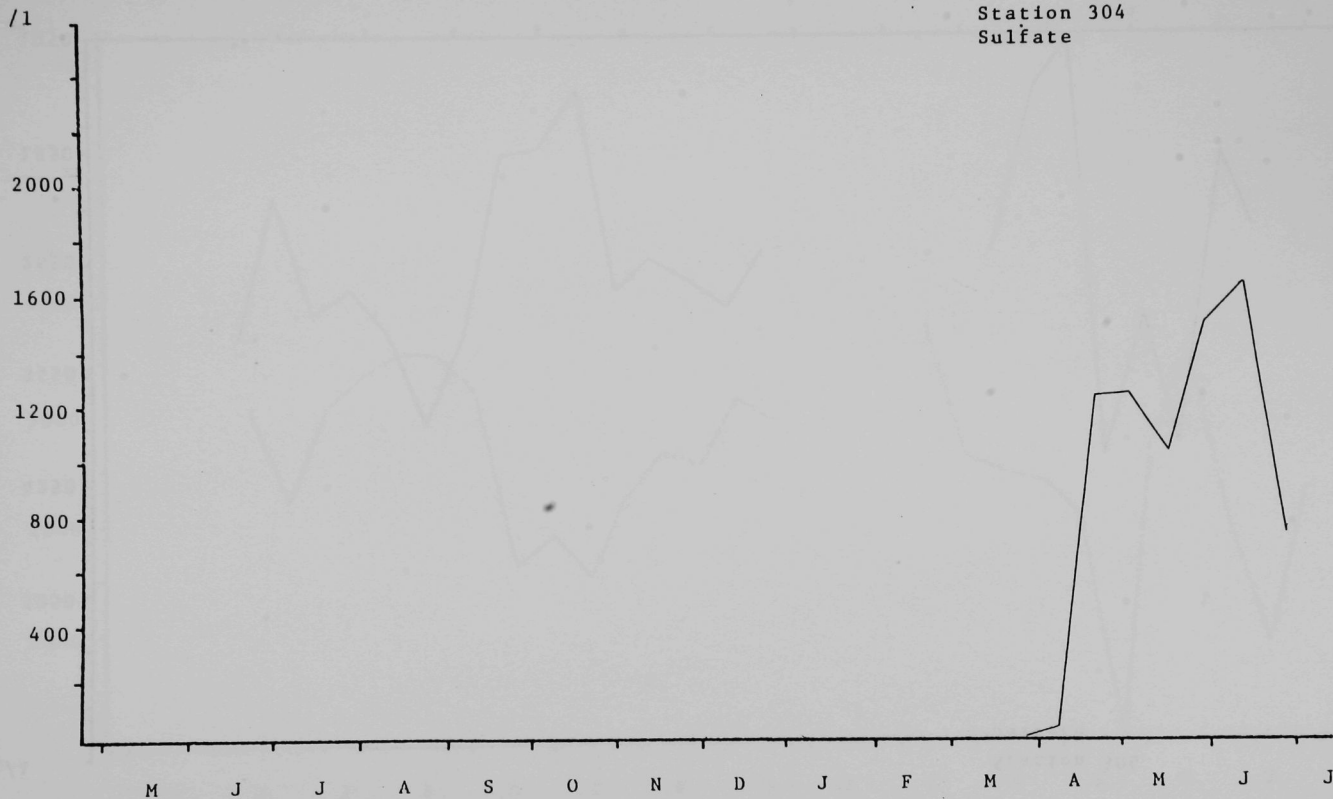


Station 302
Sulfate

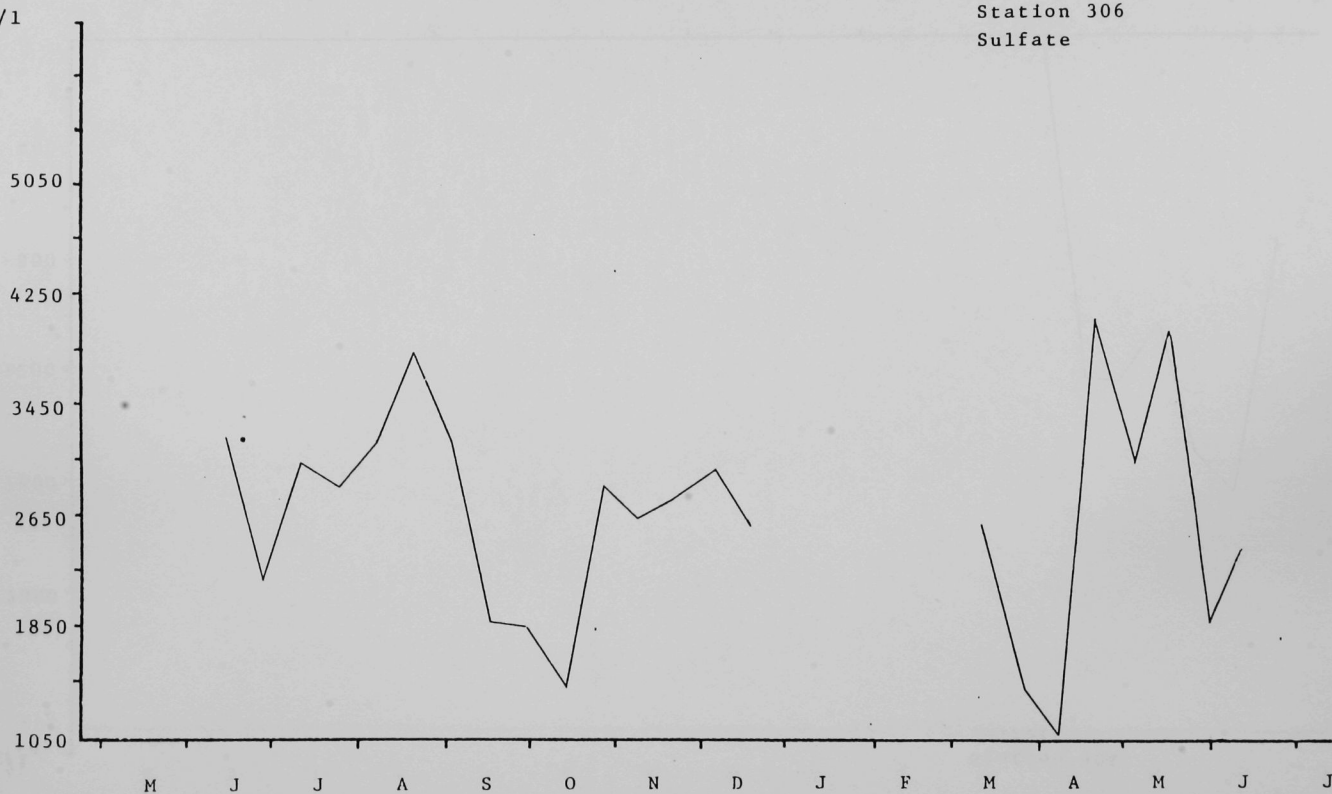


Station 303
Sulfate





Station 306
Sulfate



mg/l

Station 307
Sulfate

4000

3000

2000

1000

M

J

J

A

S

O

N

D

J

F

M

A

M

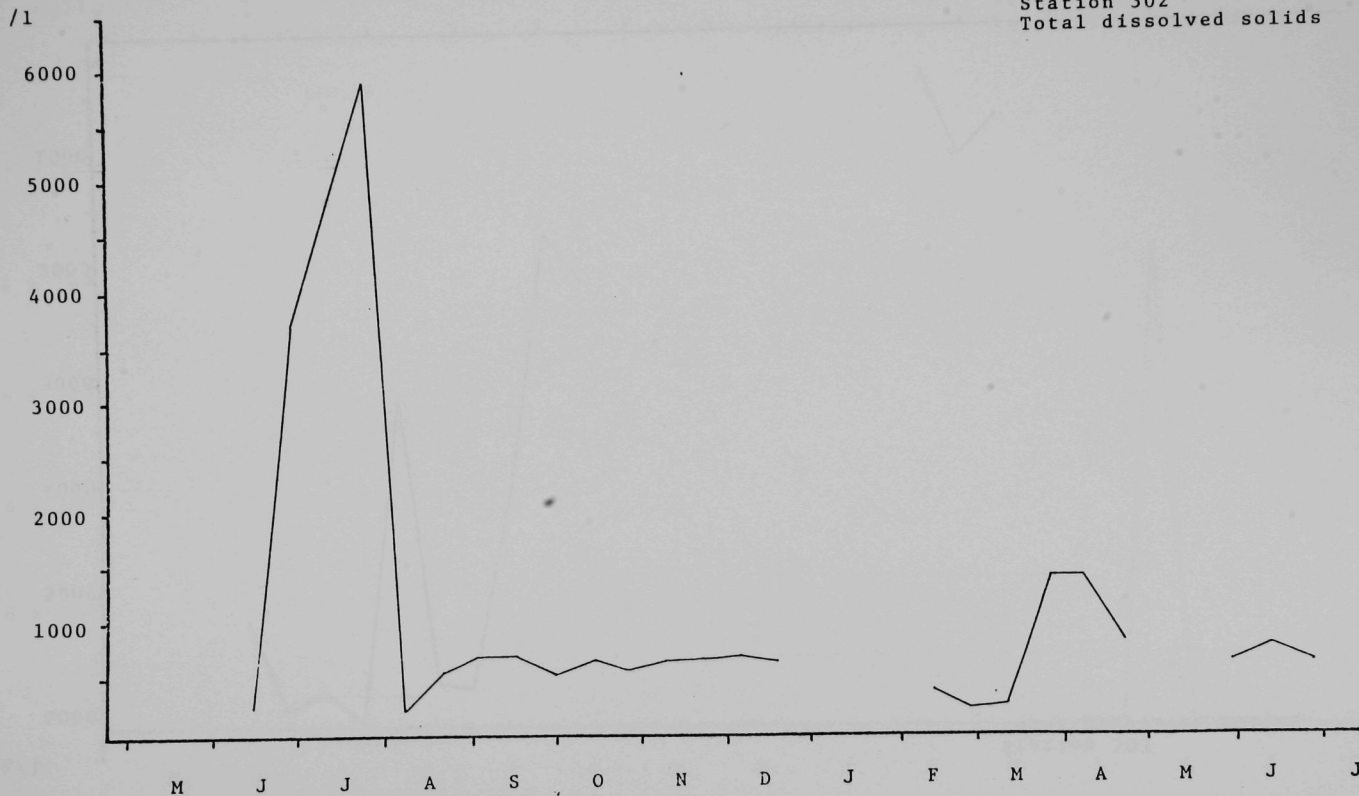
J

J

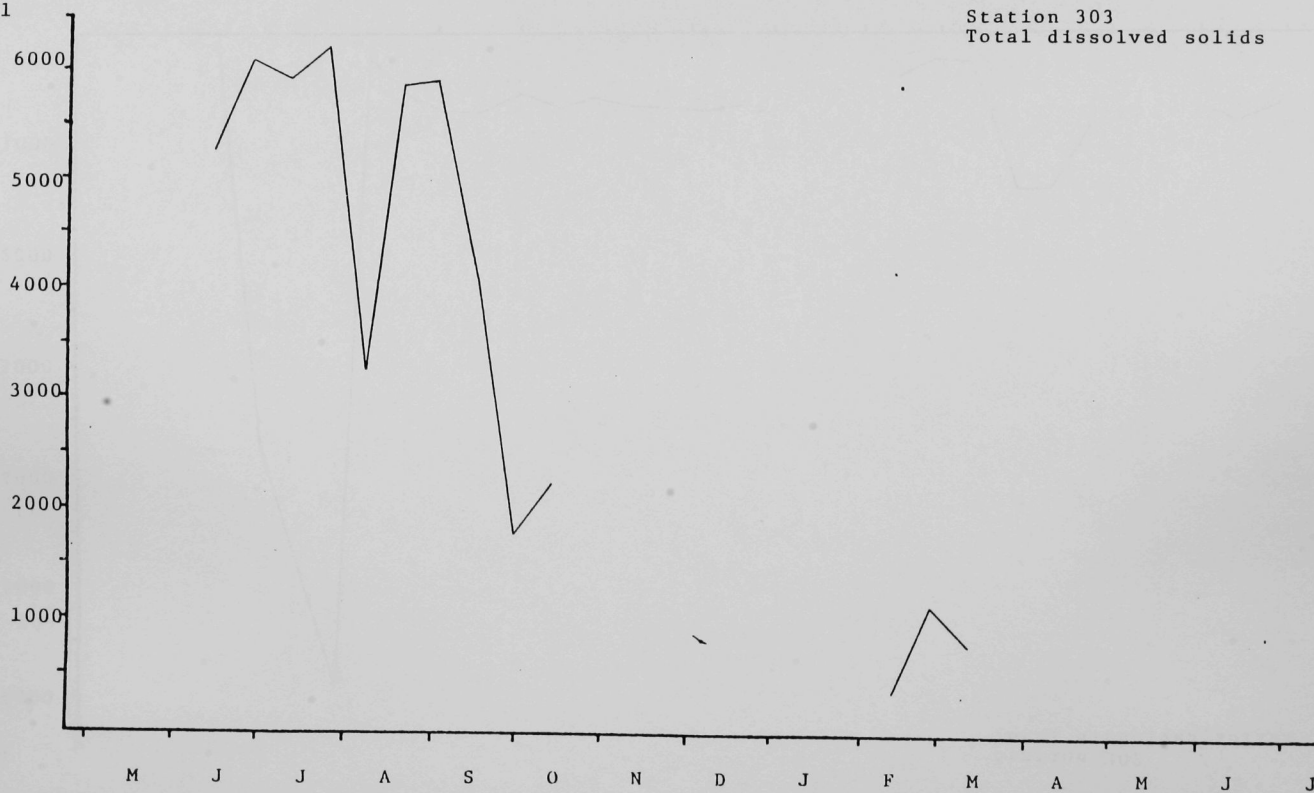
139



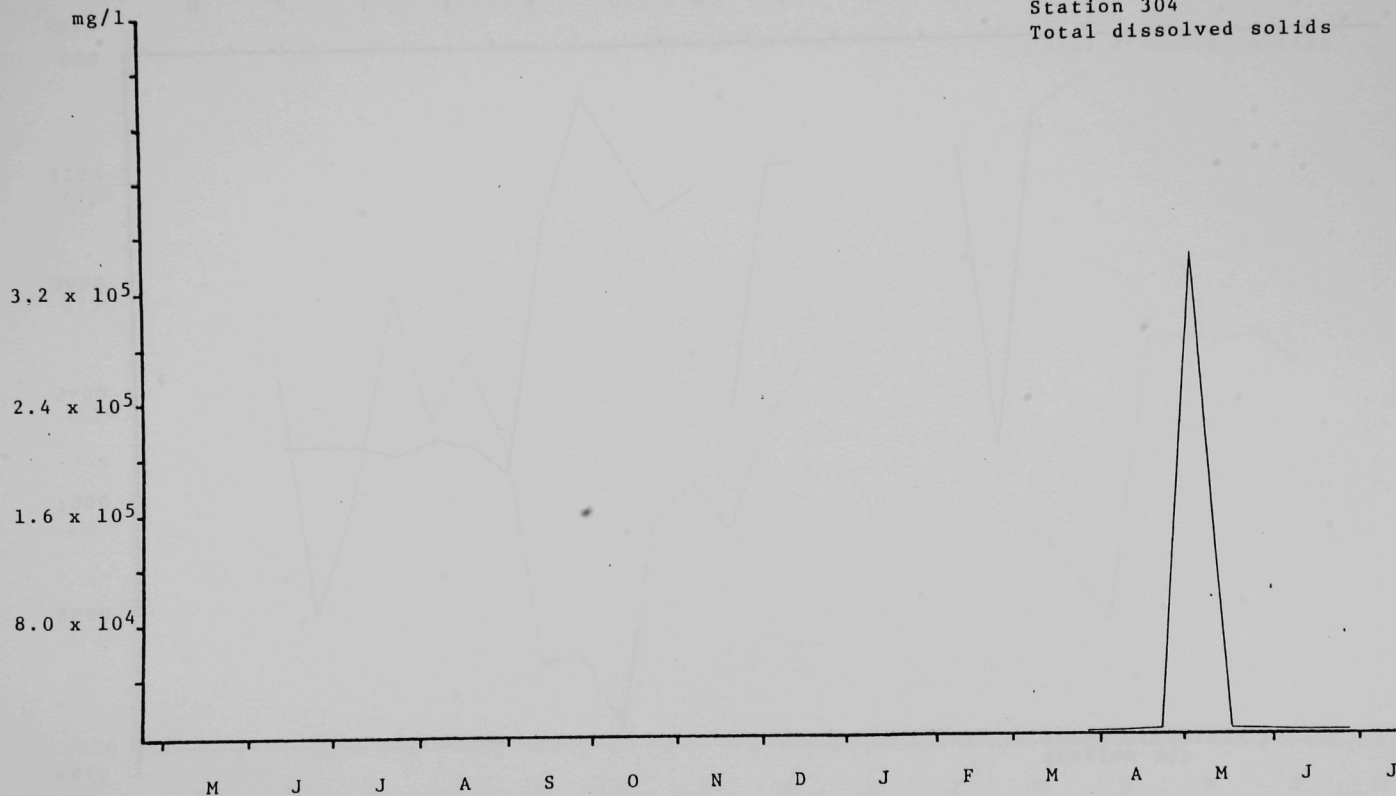
Station 302
Total dissolved solids

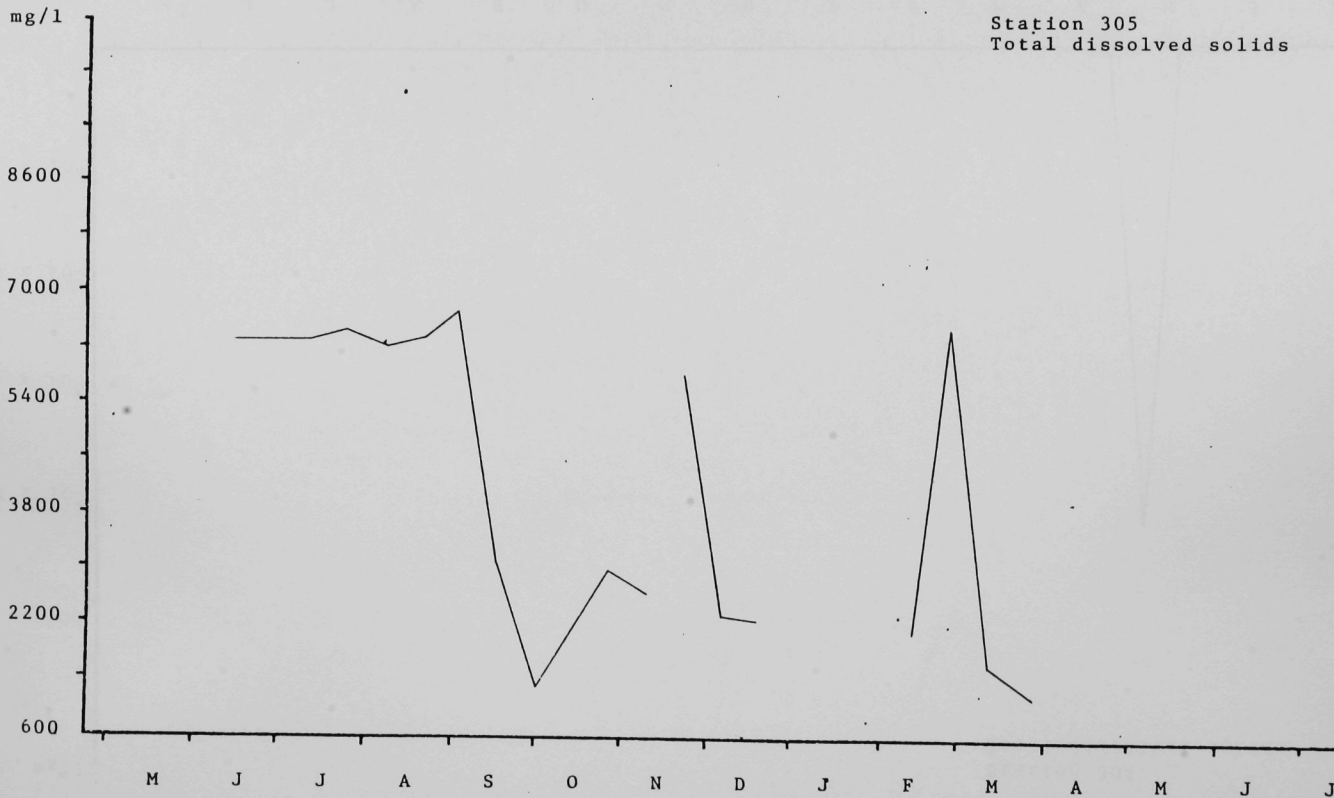


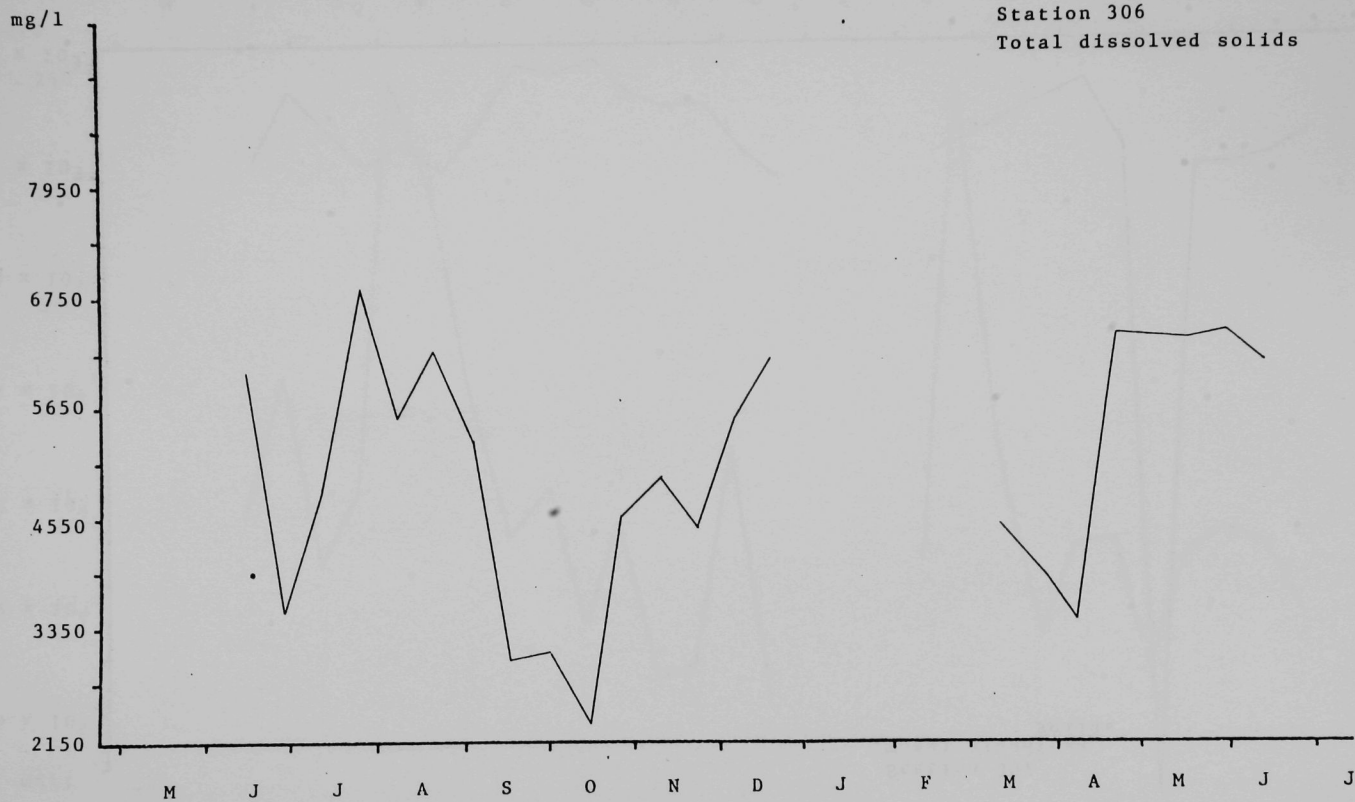
mg/l

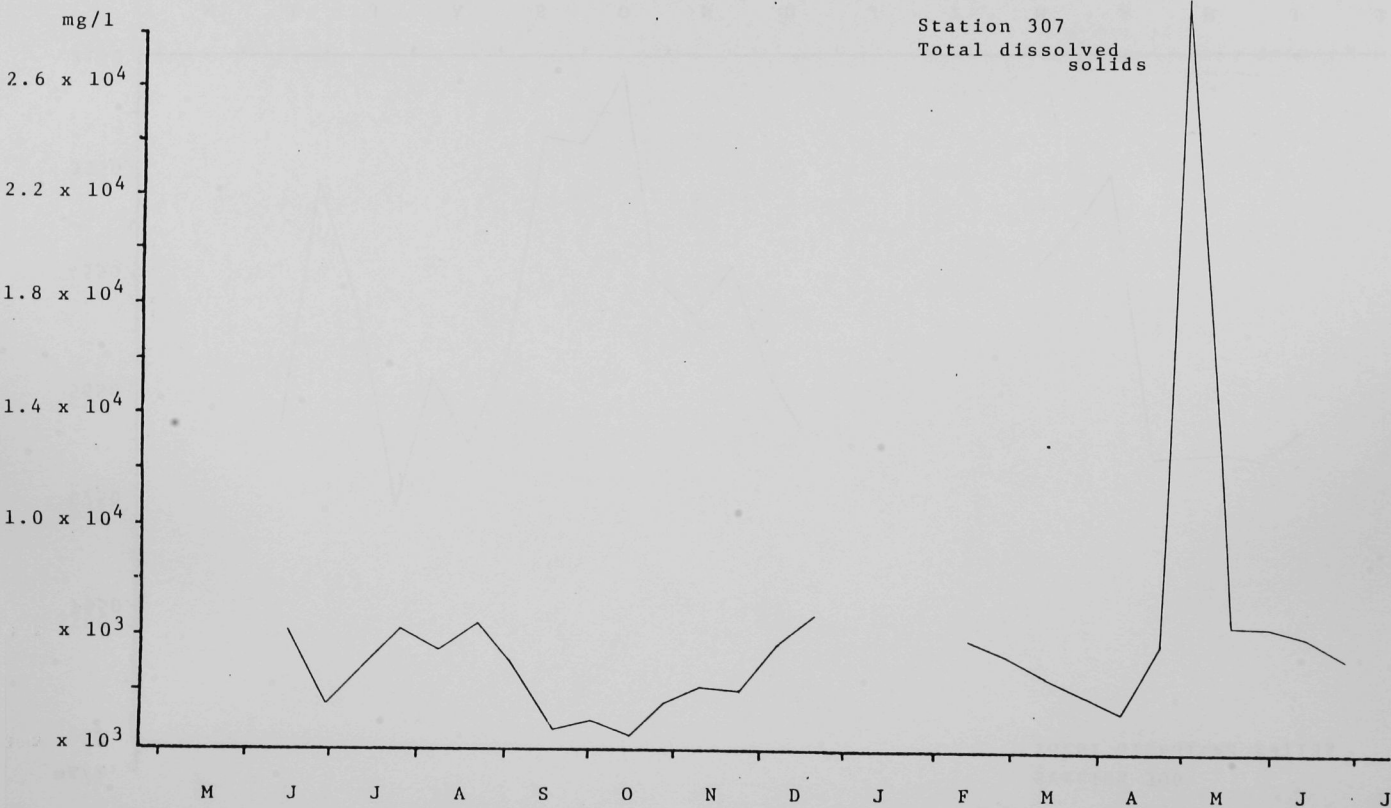


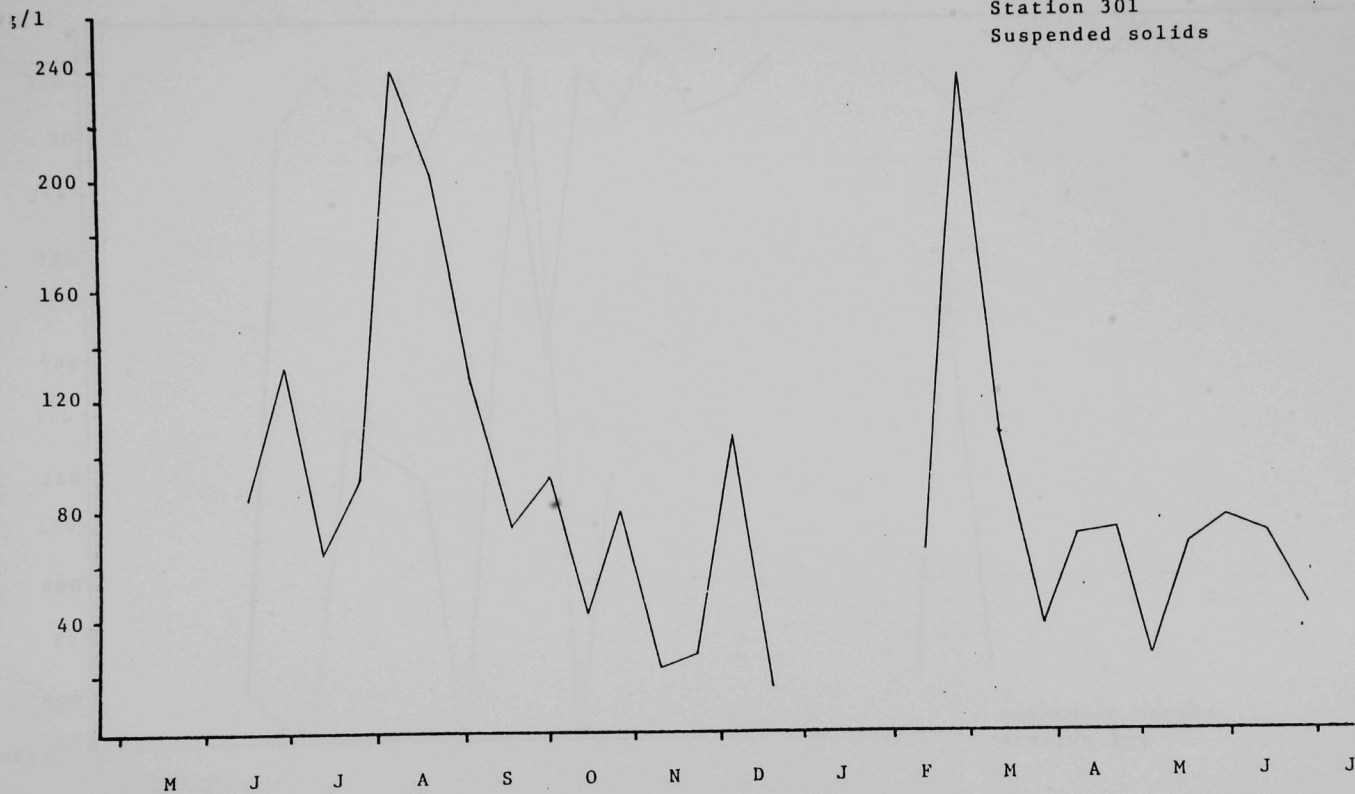
Station 304
Total dissolved solids





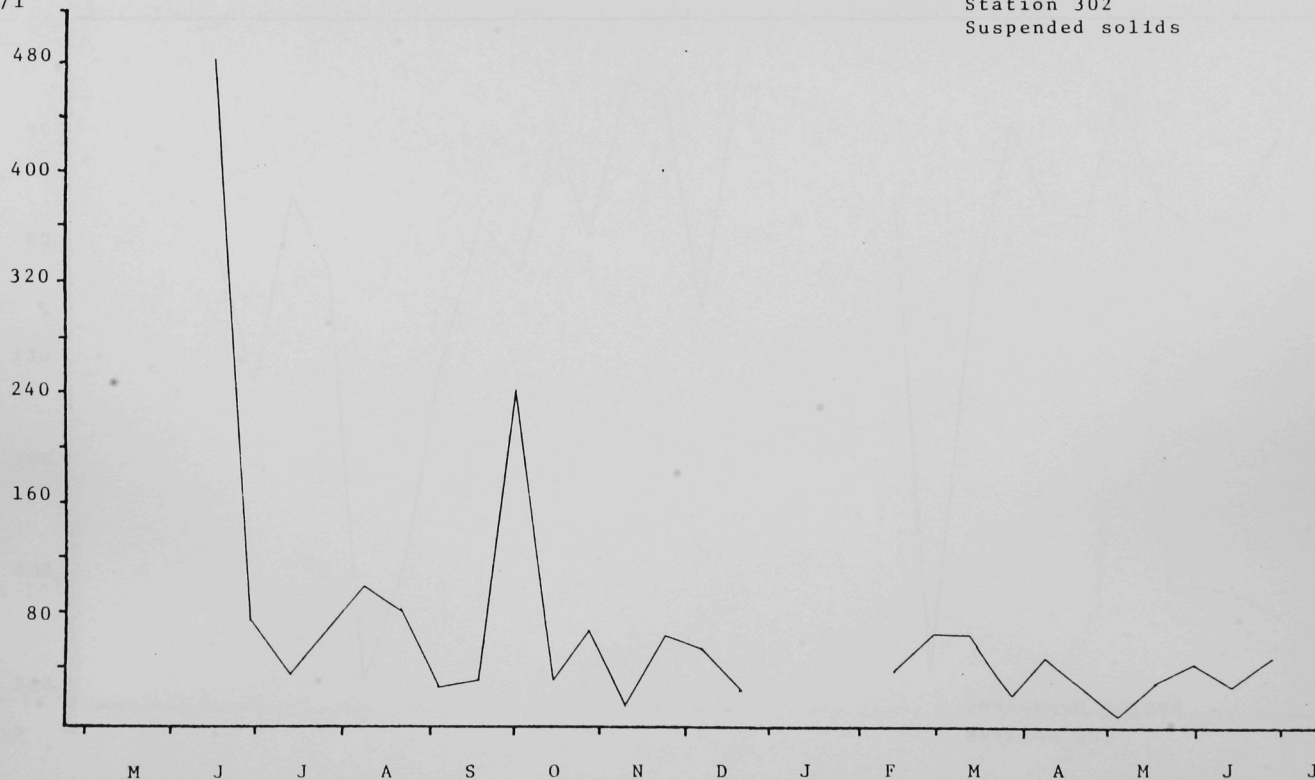




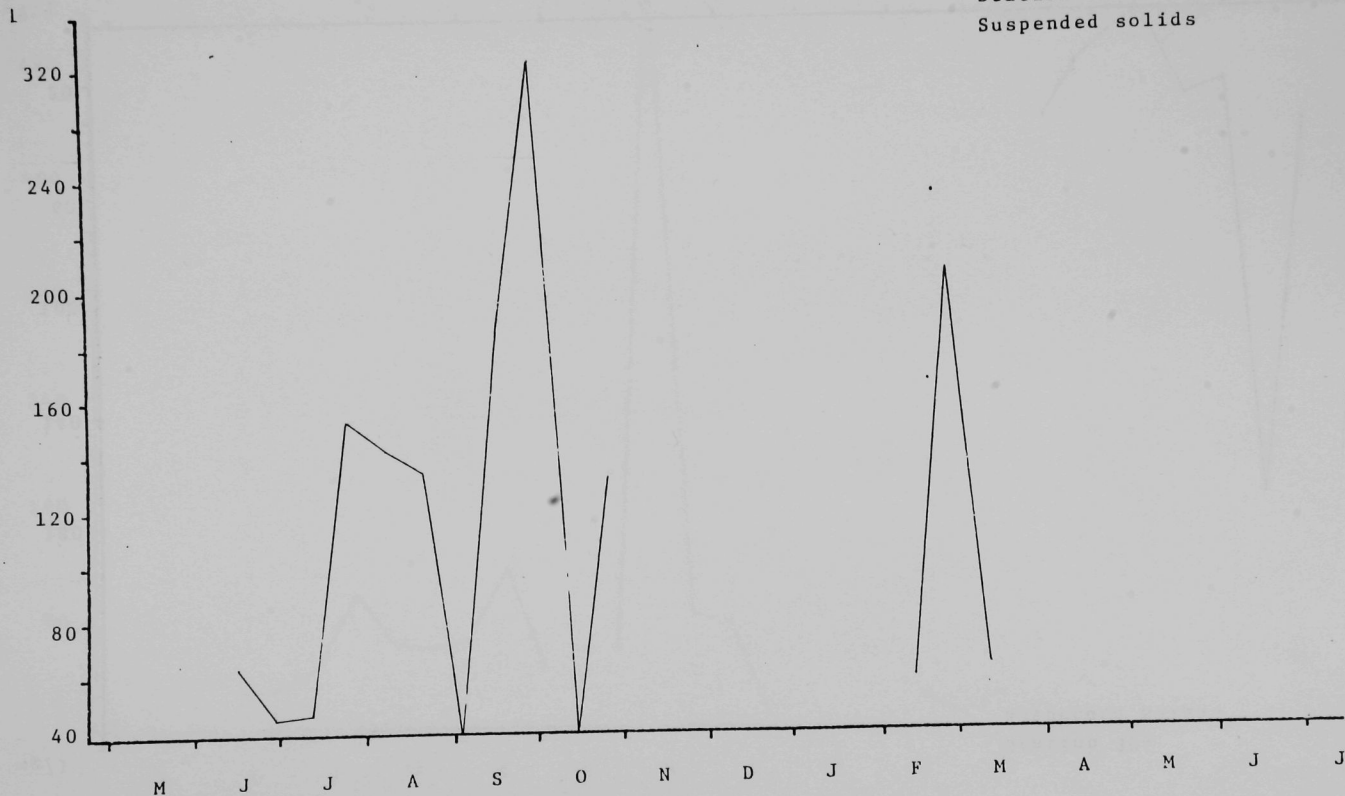


mg/l

Station 302
Suspended solids



Station 303
Suspended solids



mg/l

Station 304

Suspended solids

180

140

100

60

20

M

J

J

A

S

O

N

D

J

F

M

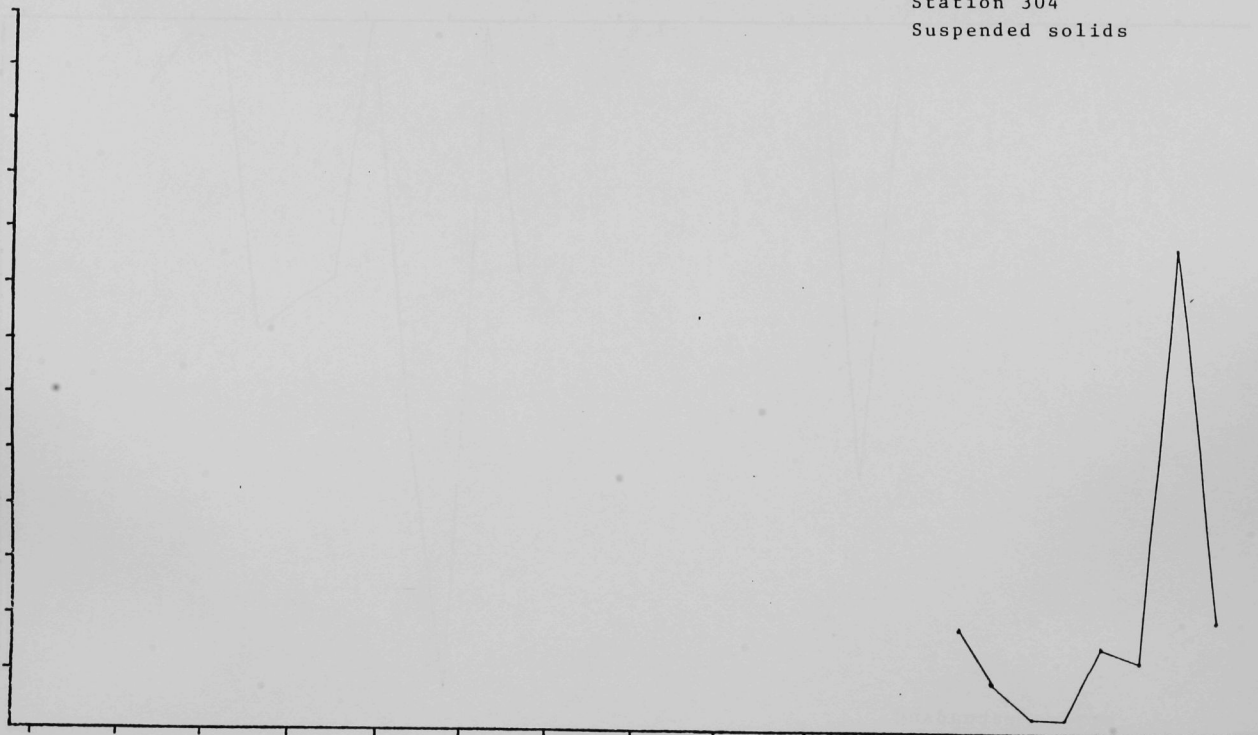
A

M

J

J

150



mg/l

Station 305
Suspended solids

480

400

320

240

160

80

M

J

J

A

S

O

N

D

J

F

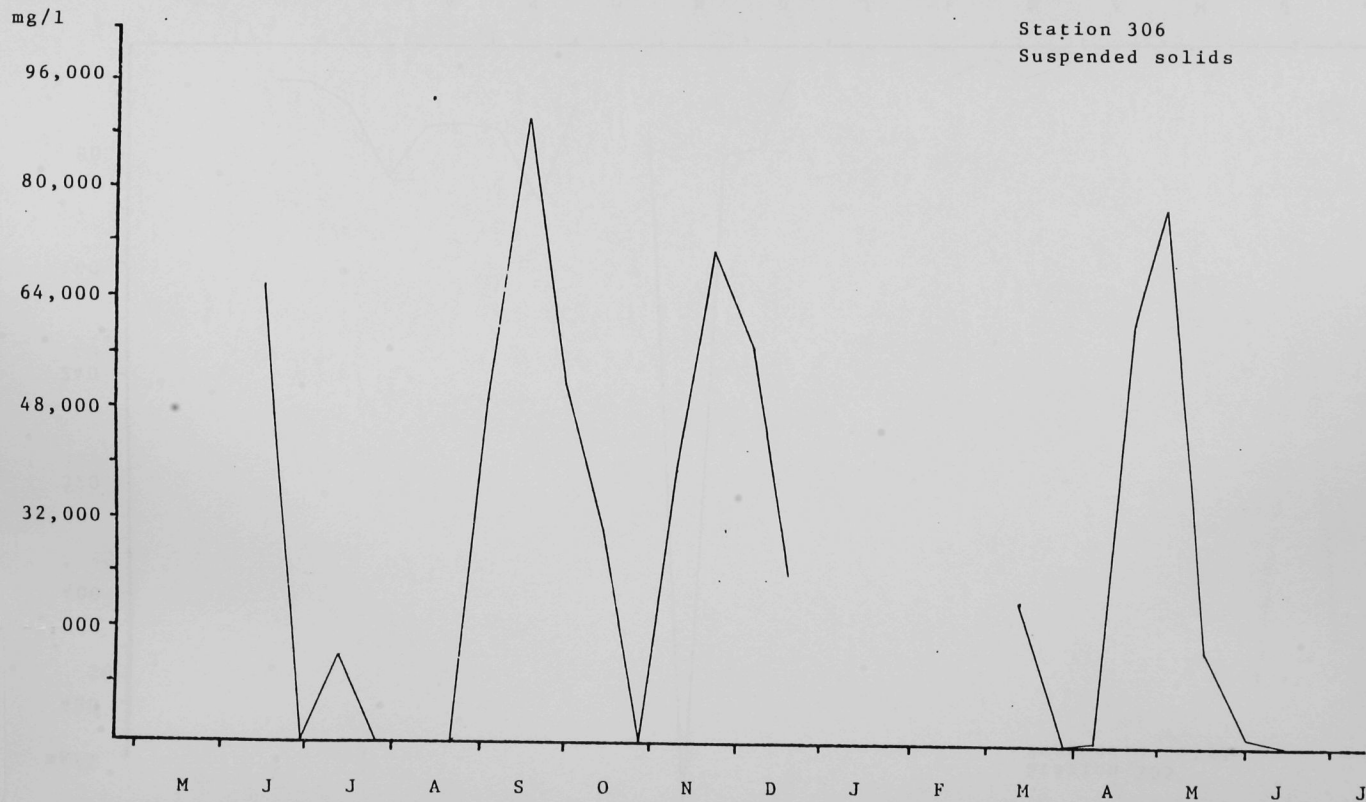
M

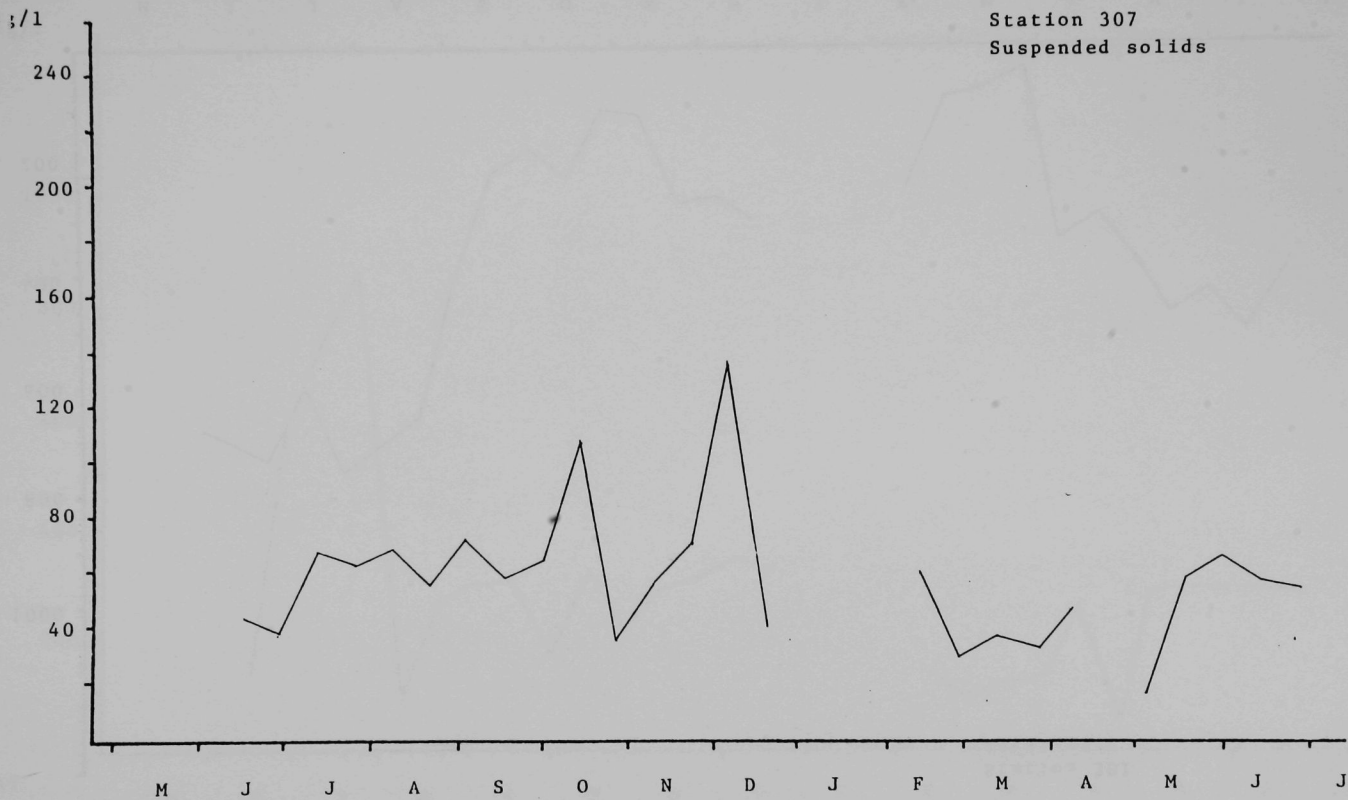
A

M

J

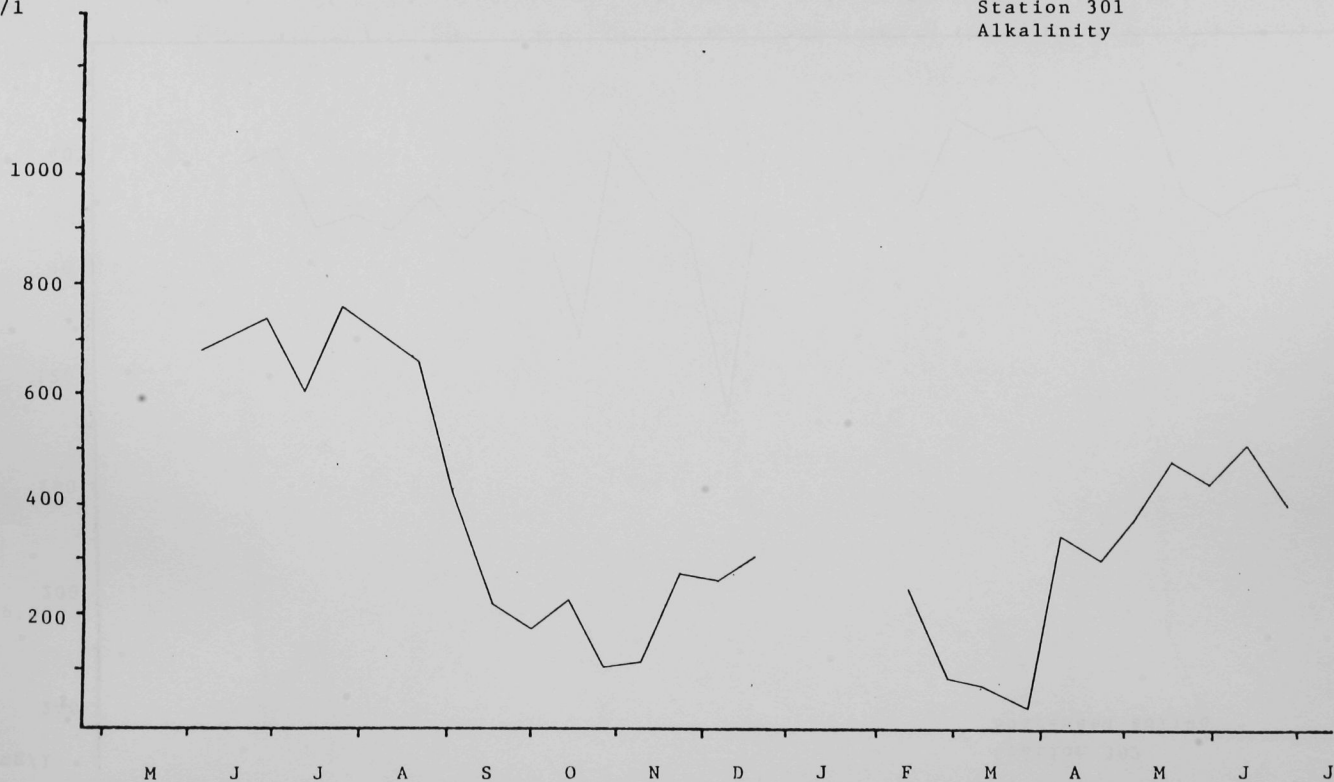
J





mg/l

Station 301
Alkalinity



g/l

Station 302
Alkalinity

1000

800

600

400

200

M

J

J

A

S

O

N

D

J

F

M

A

M

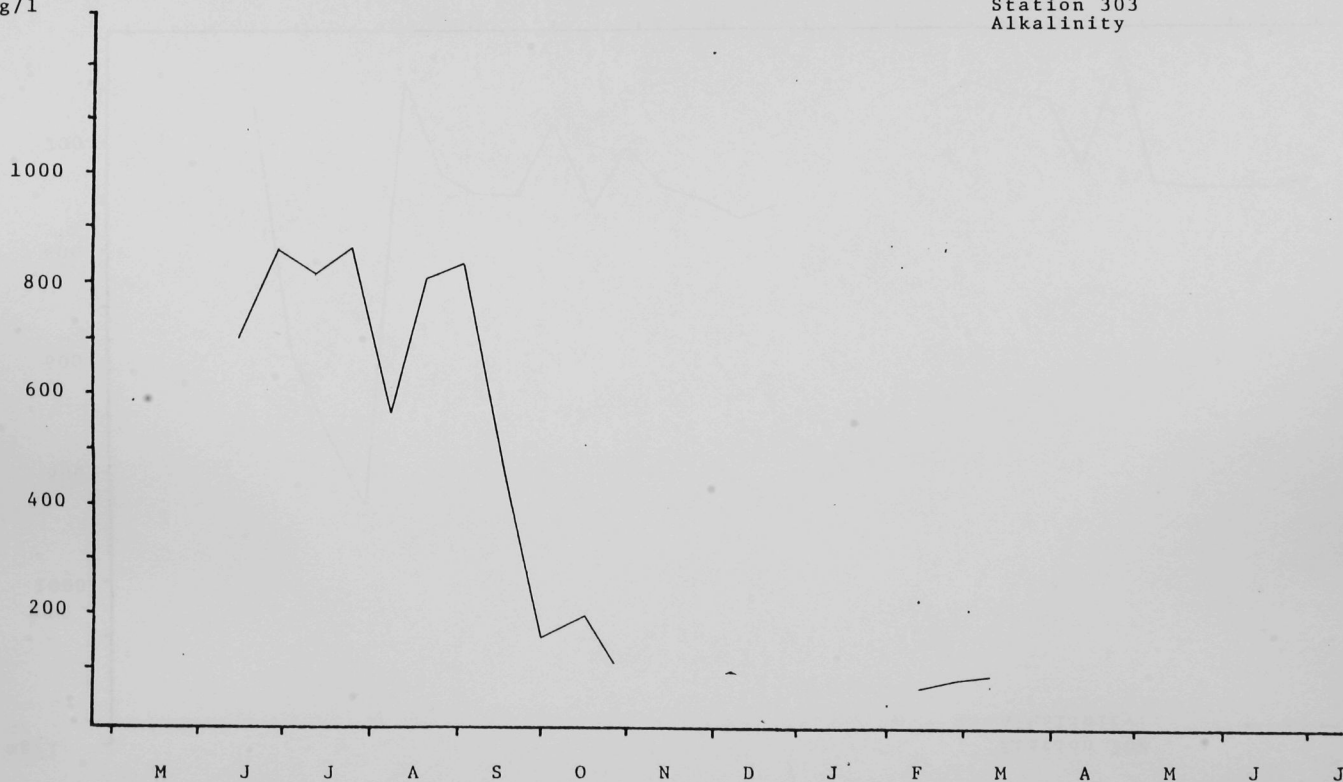
J

J

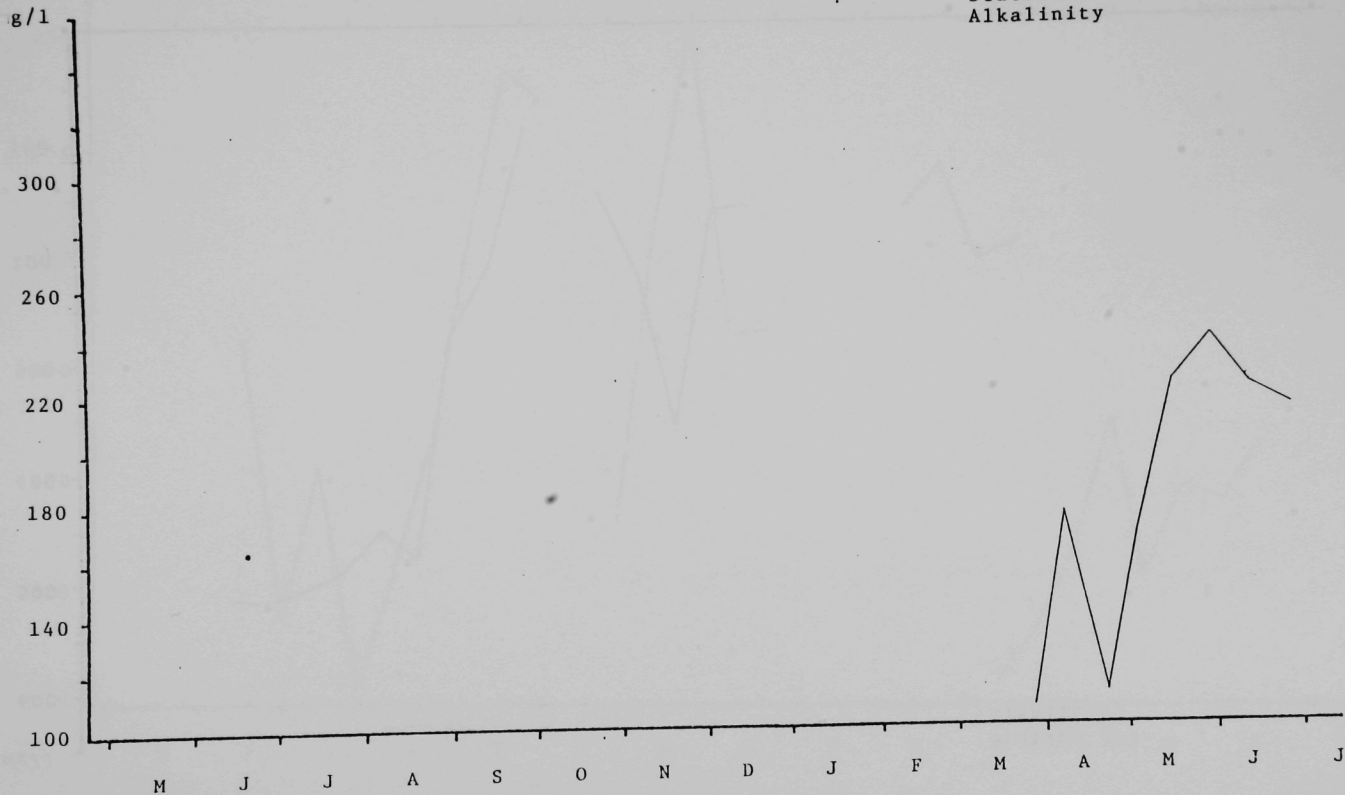
155

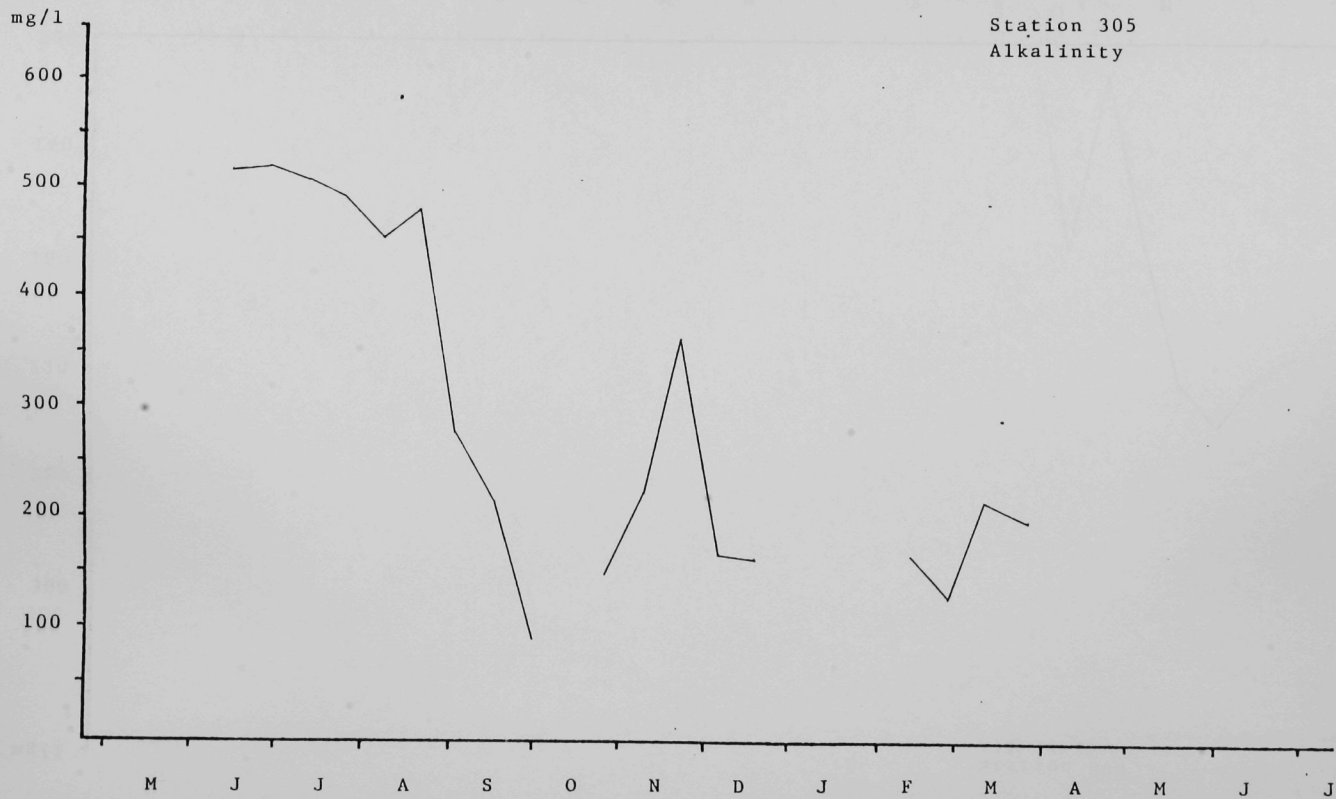
mg/l

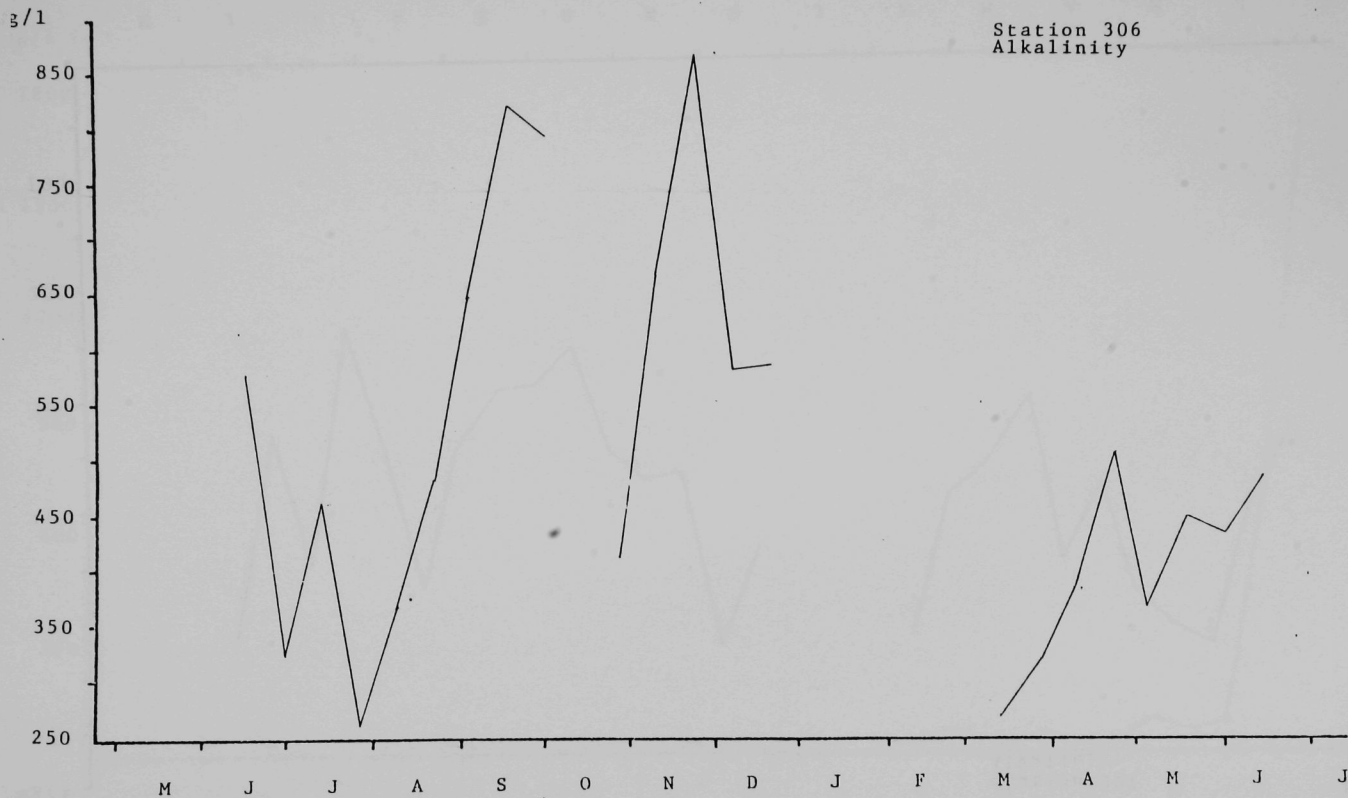
Station 303
Alkalinity



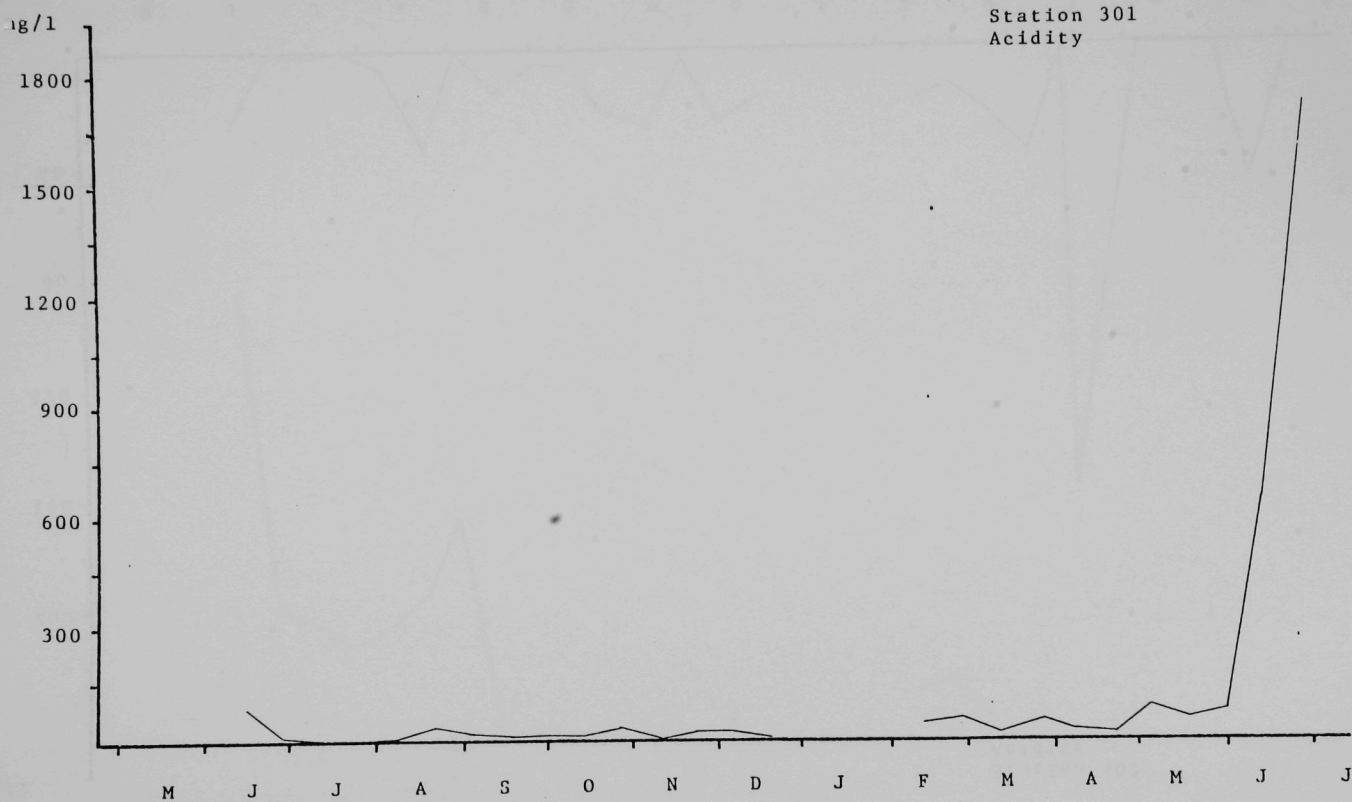
Station 304
Alkalinity





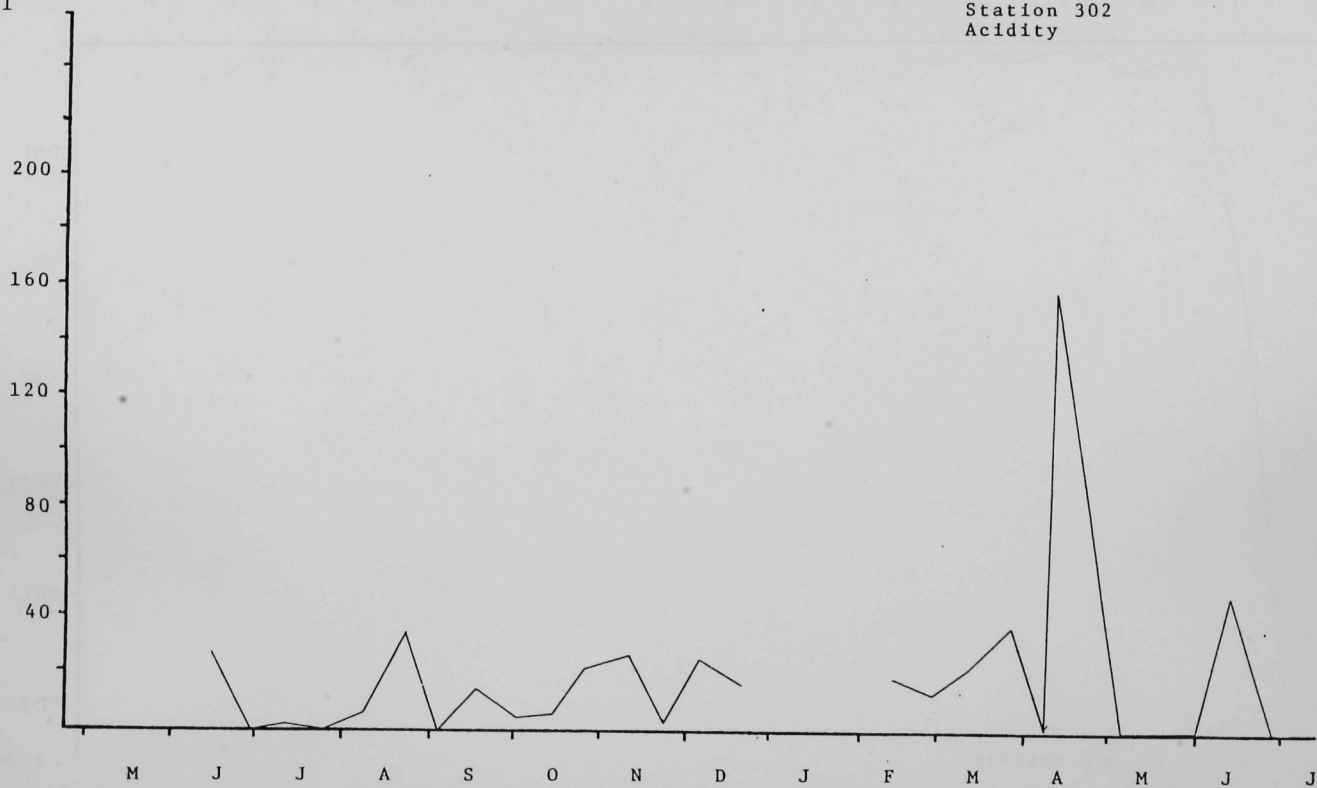




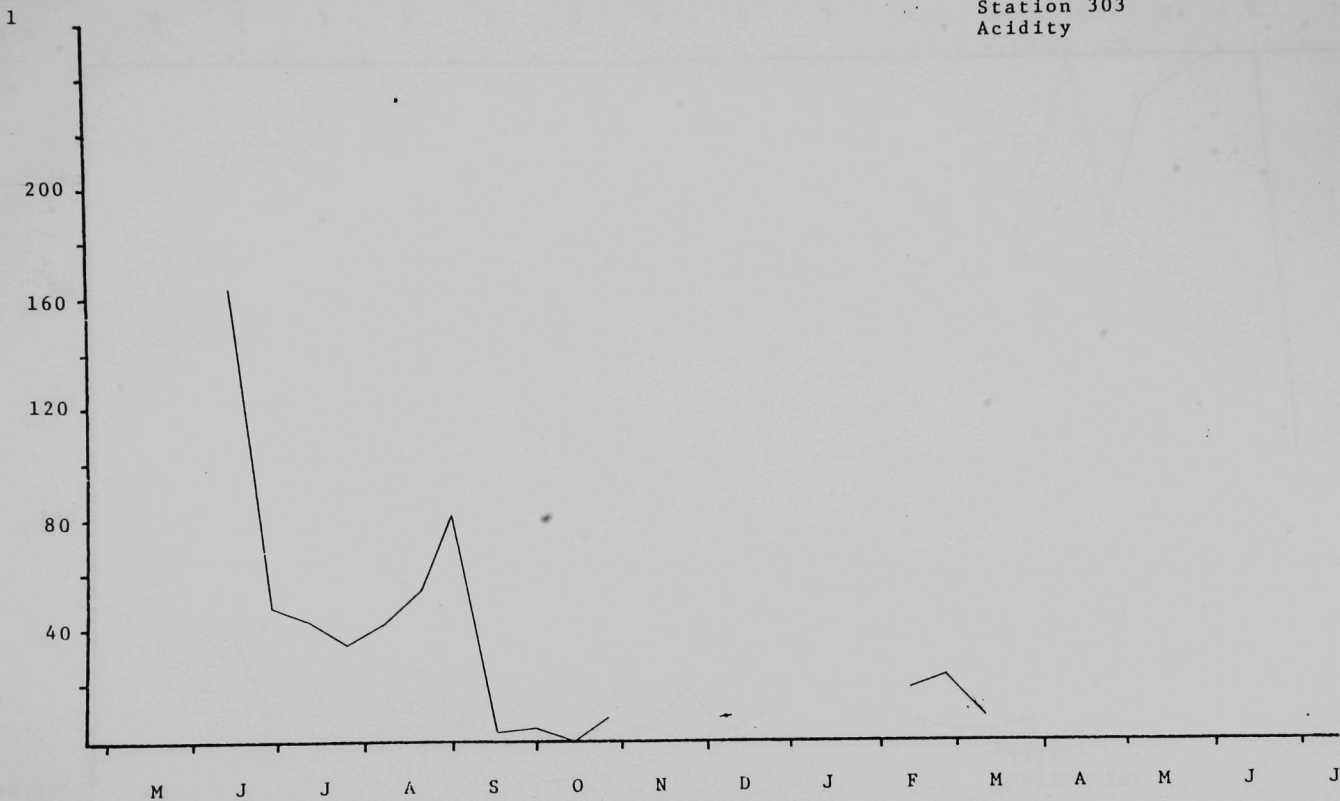


mg/l

Station 302
Acidity



Station 303
Acidity



mg/l

Station 304
Acidity

160

120

80

40

M

J

J

A

S

O

N

D

J

F

M

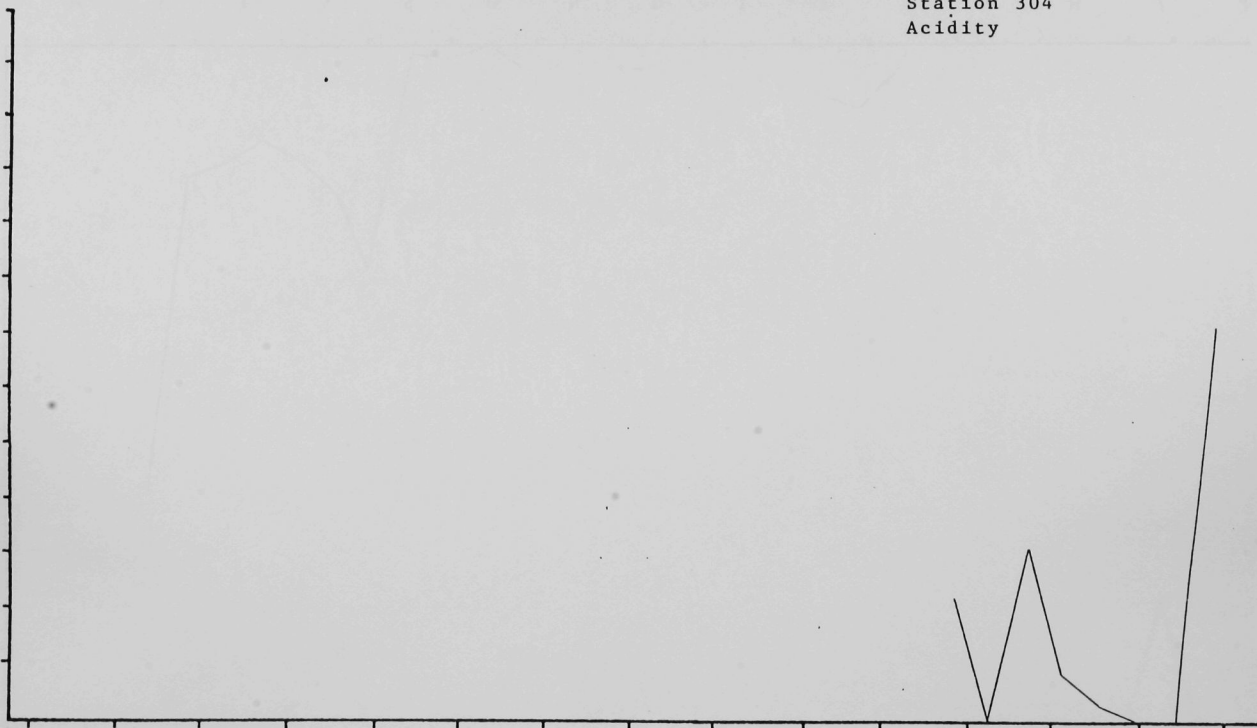
A

M

J

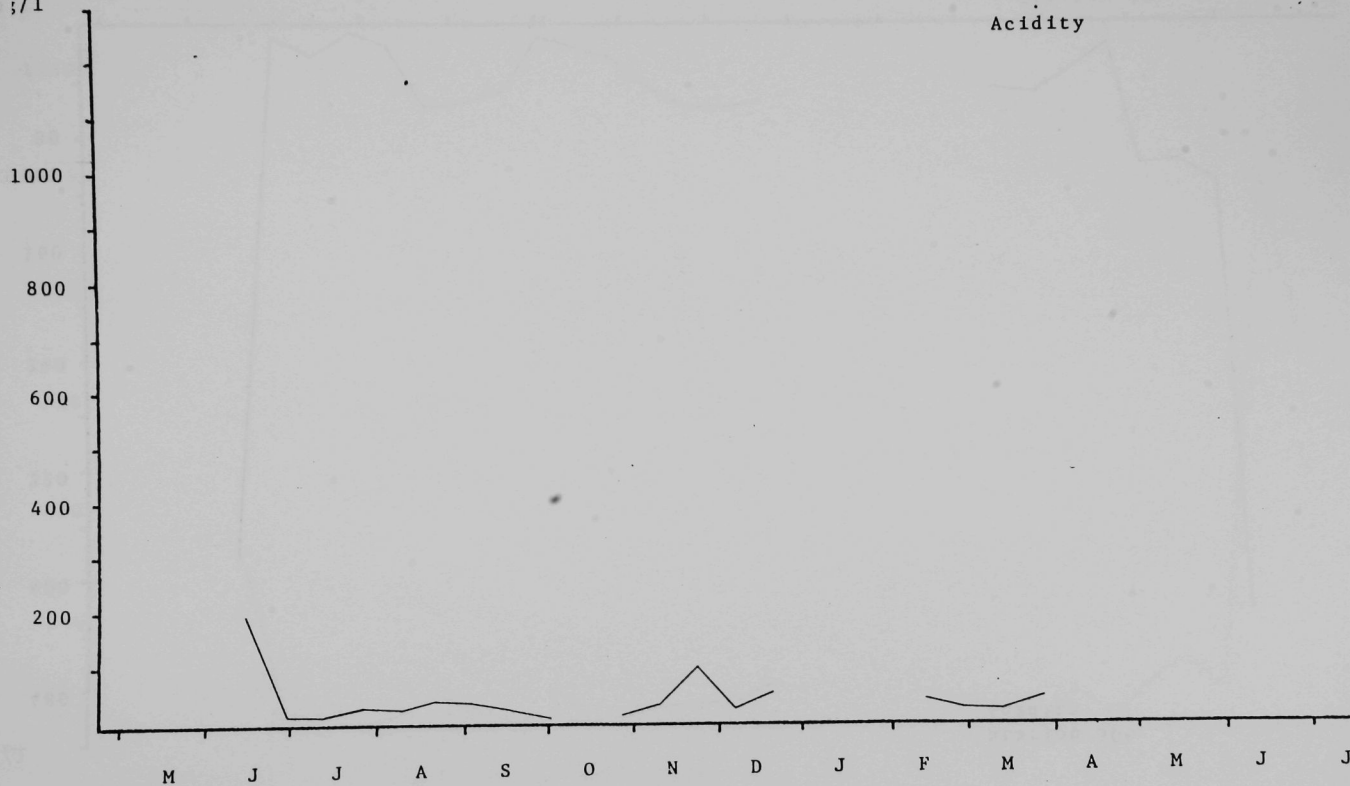
J

164

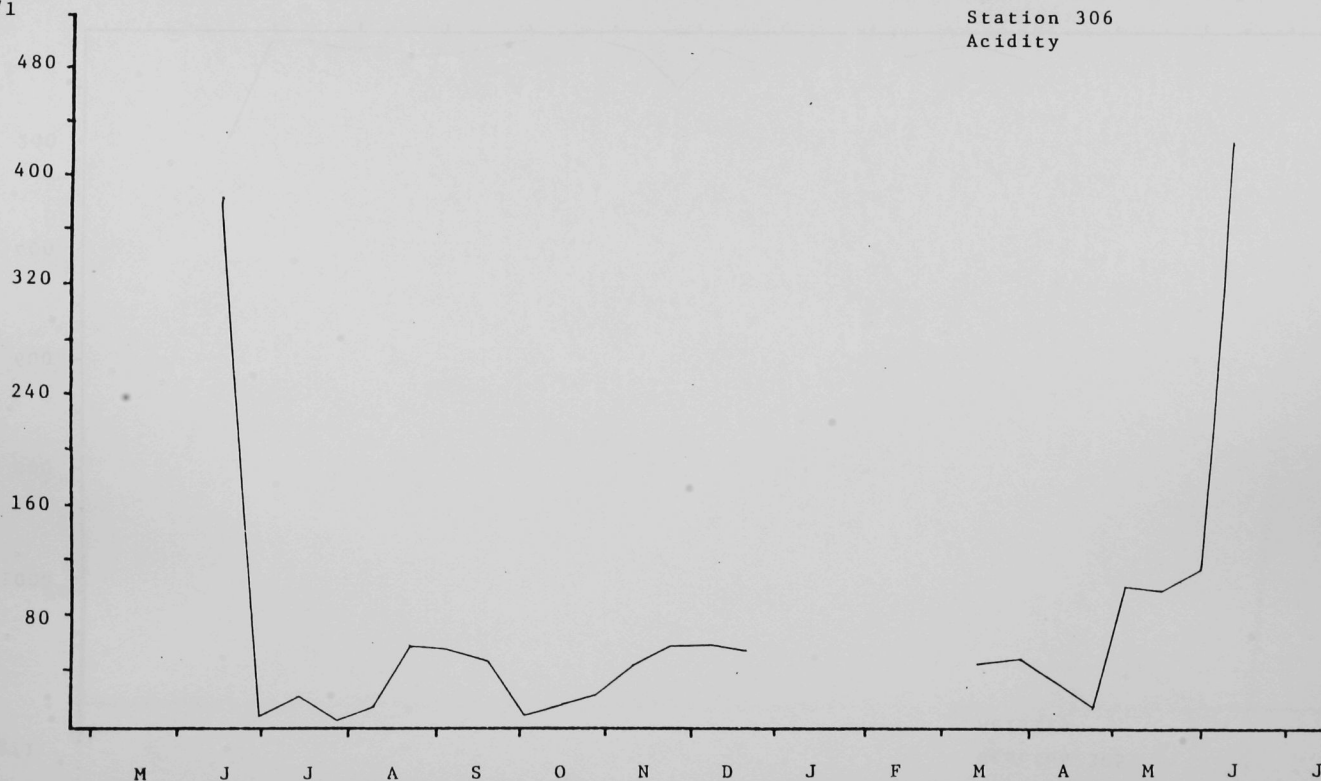


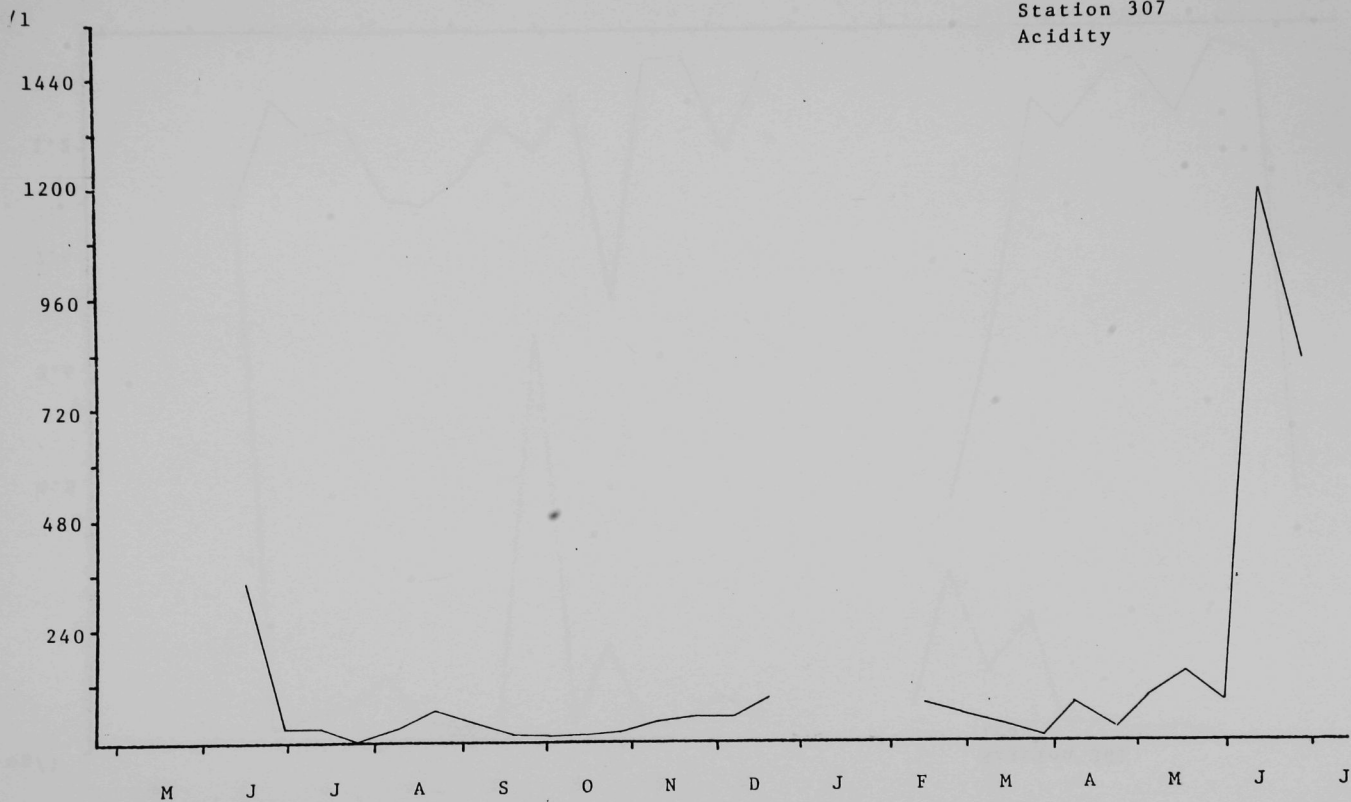
;/1

Station 305
Acidity



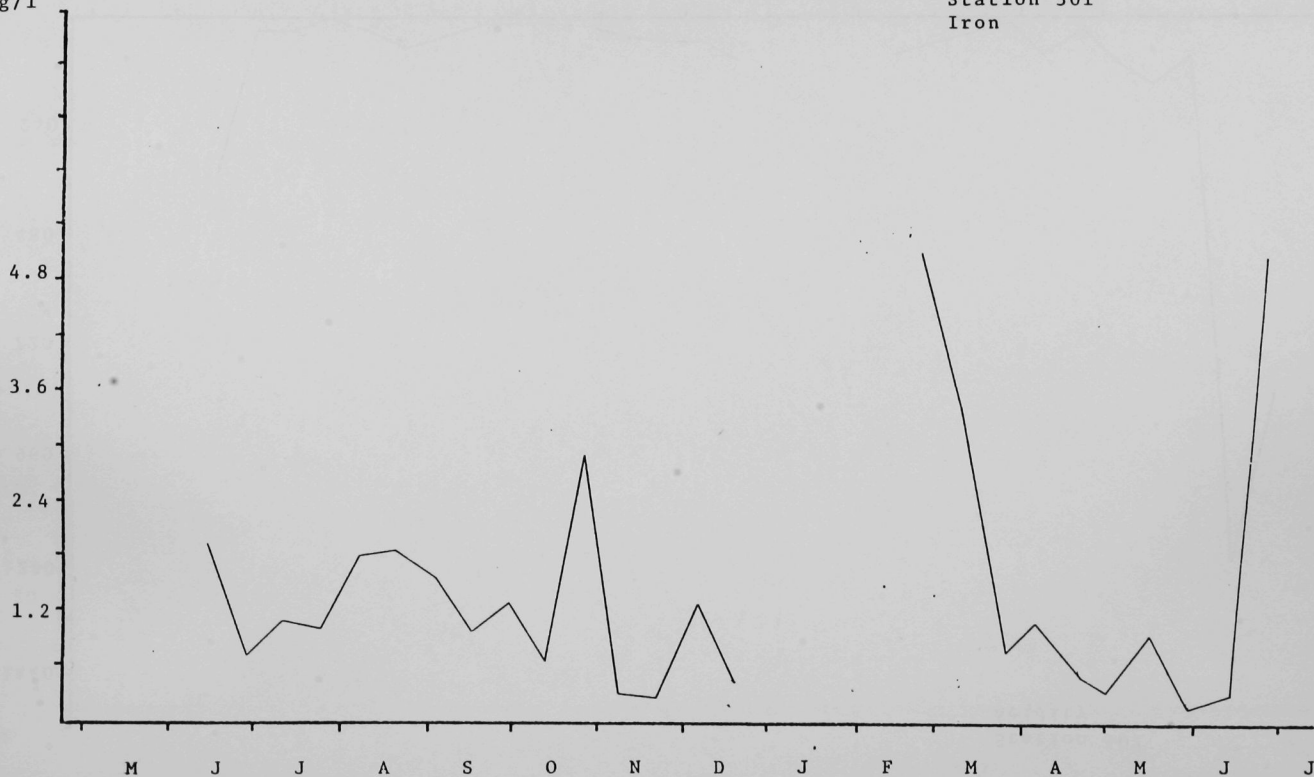
mg/l





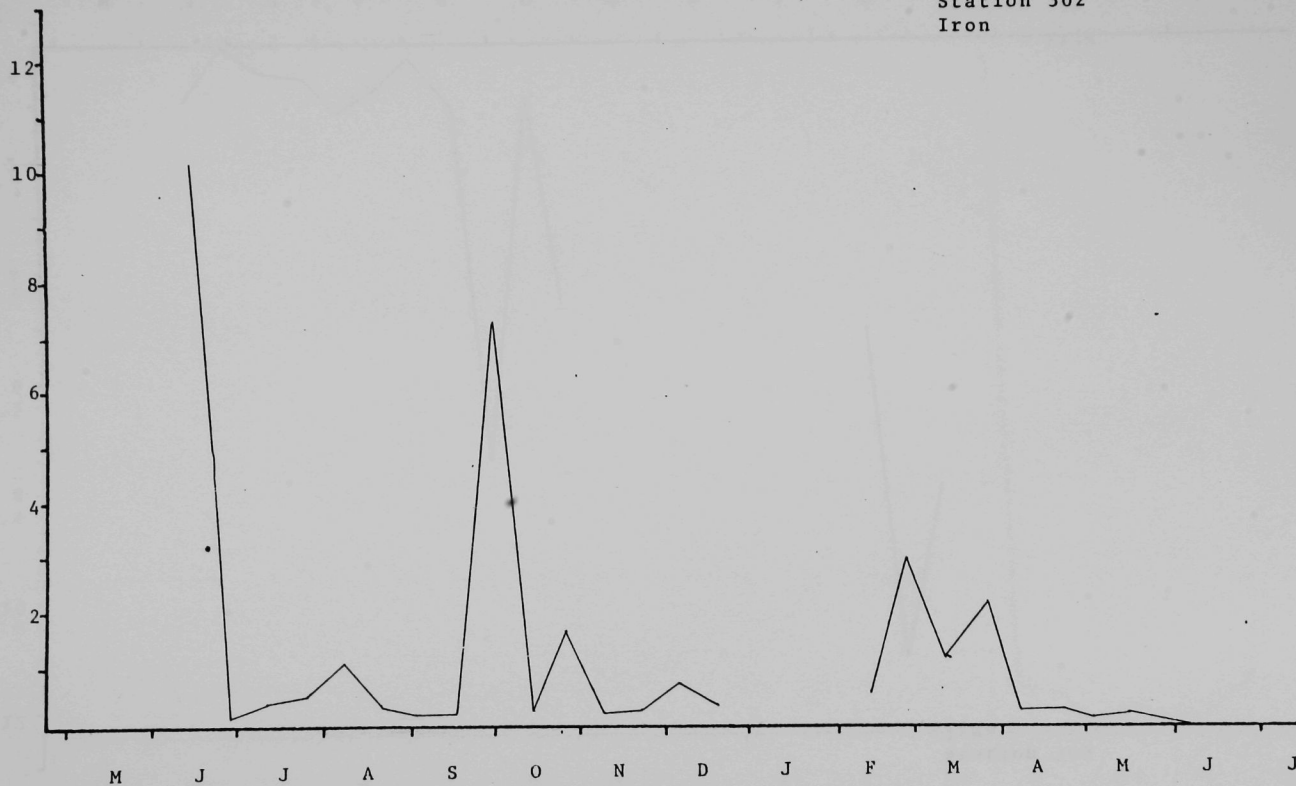
mg/l

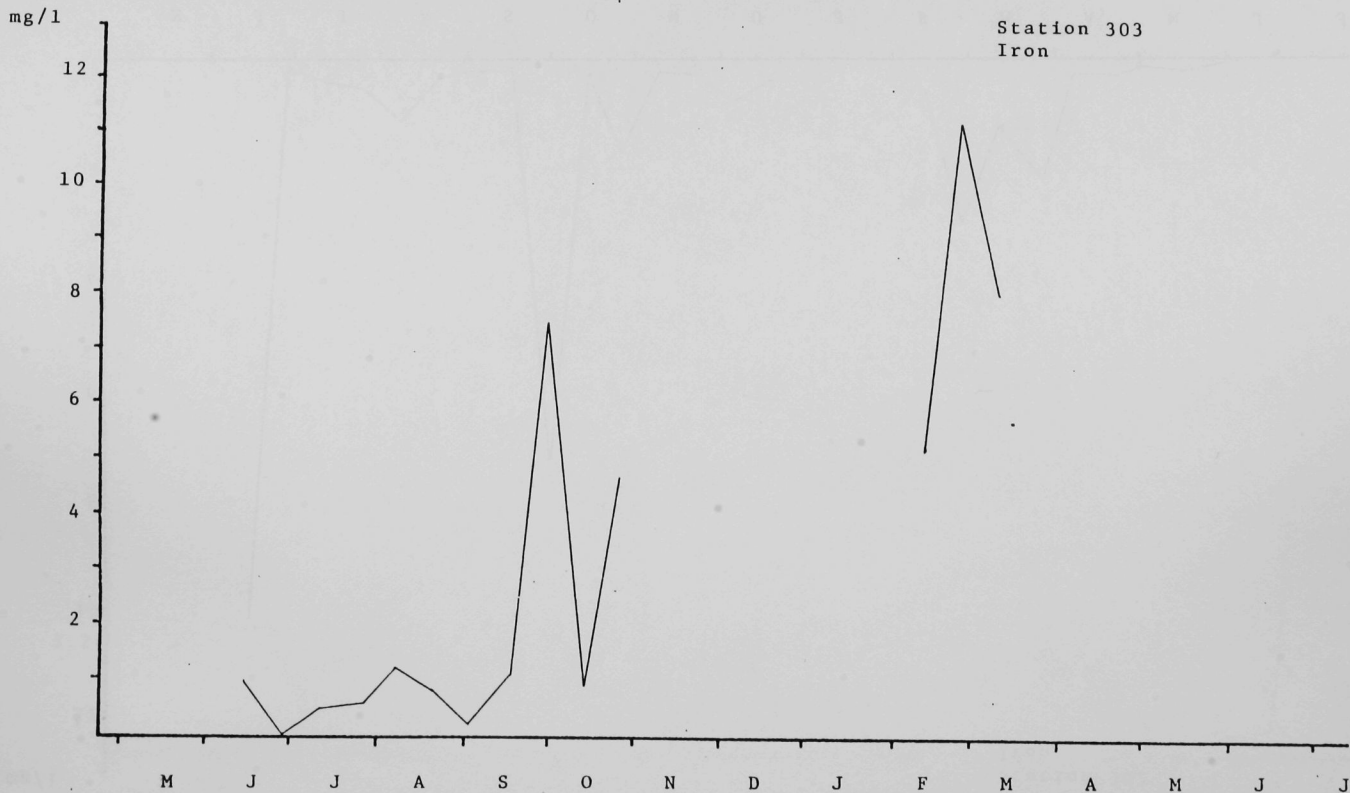
Station 301
Iron

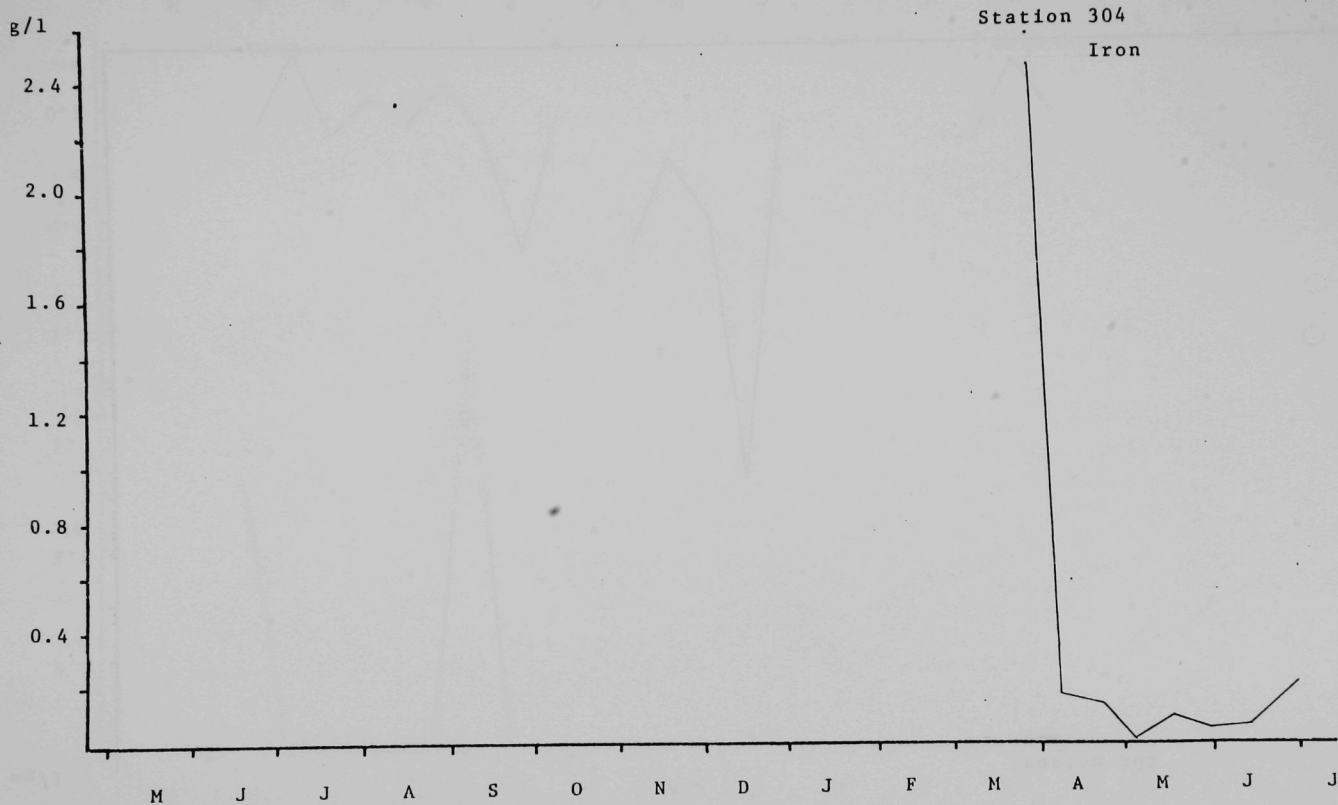


/1

Station 302
Iron

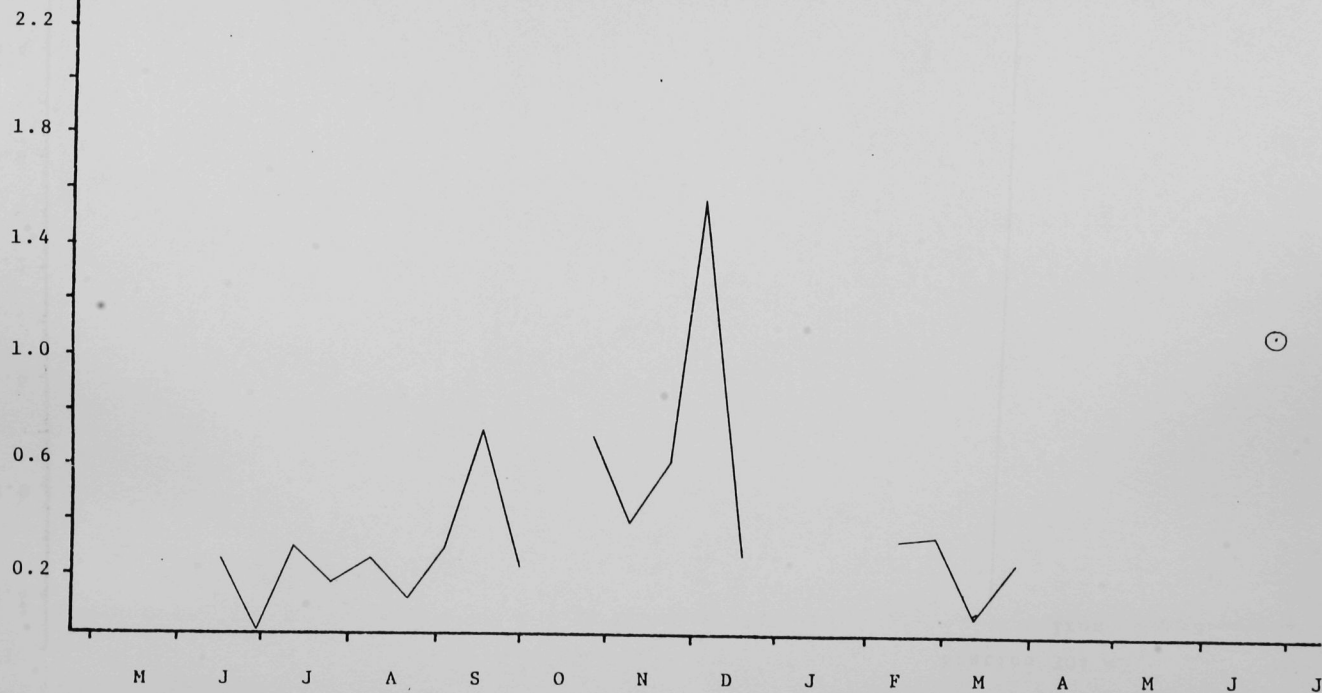




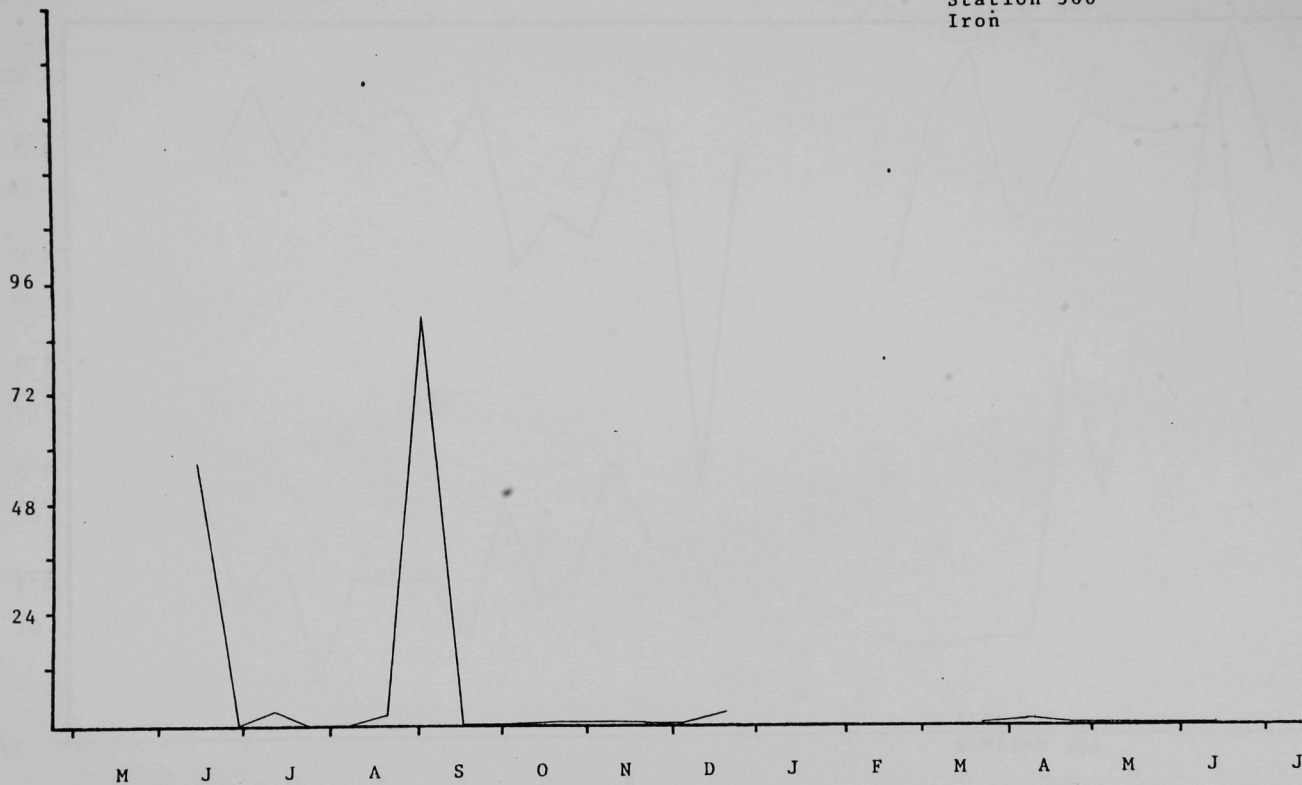


mg/l

Station 305
Iron



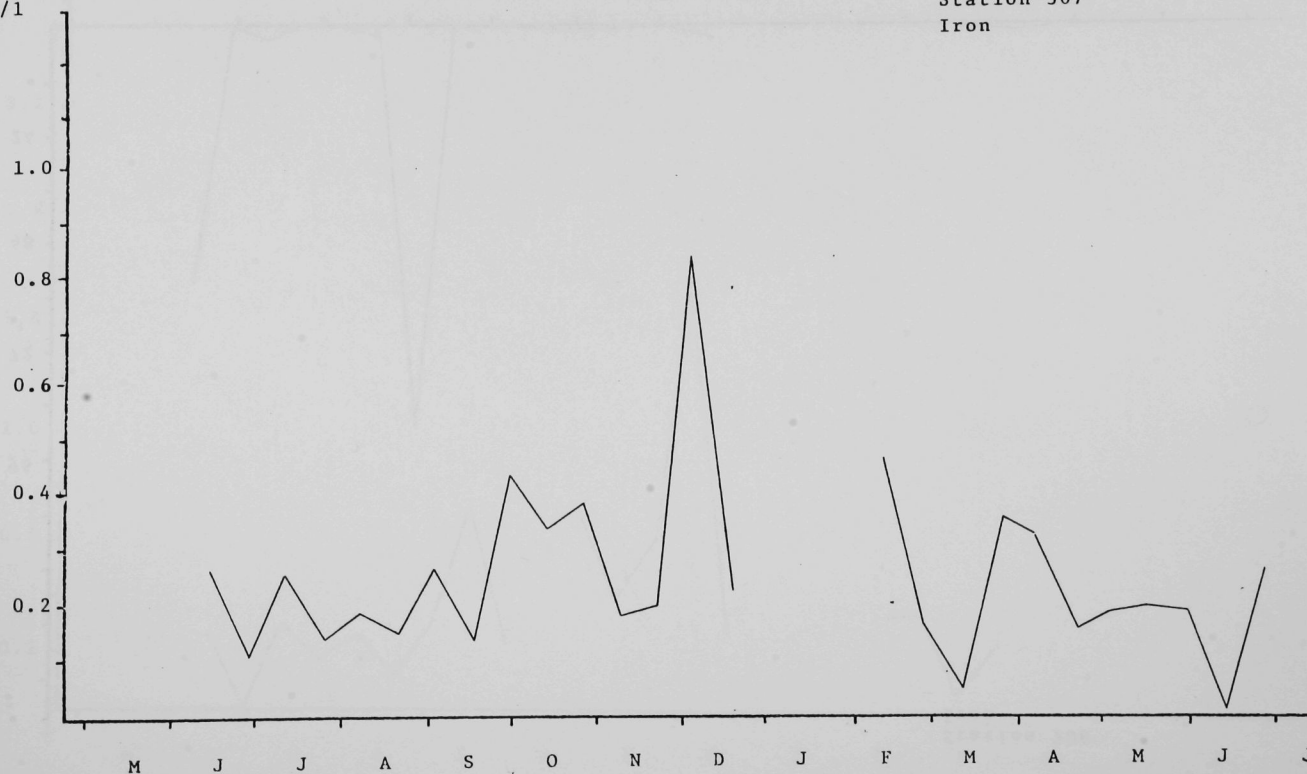
/1

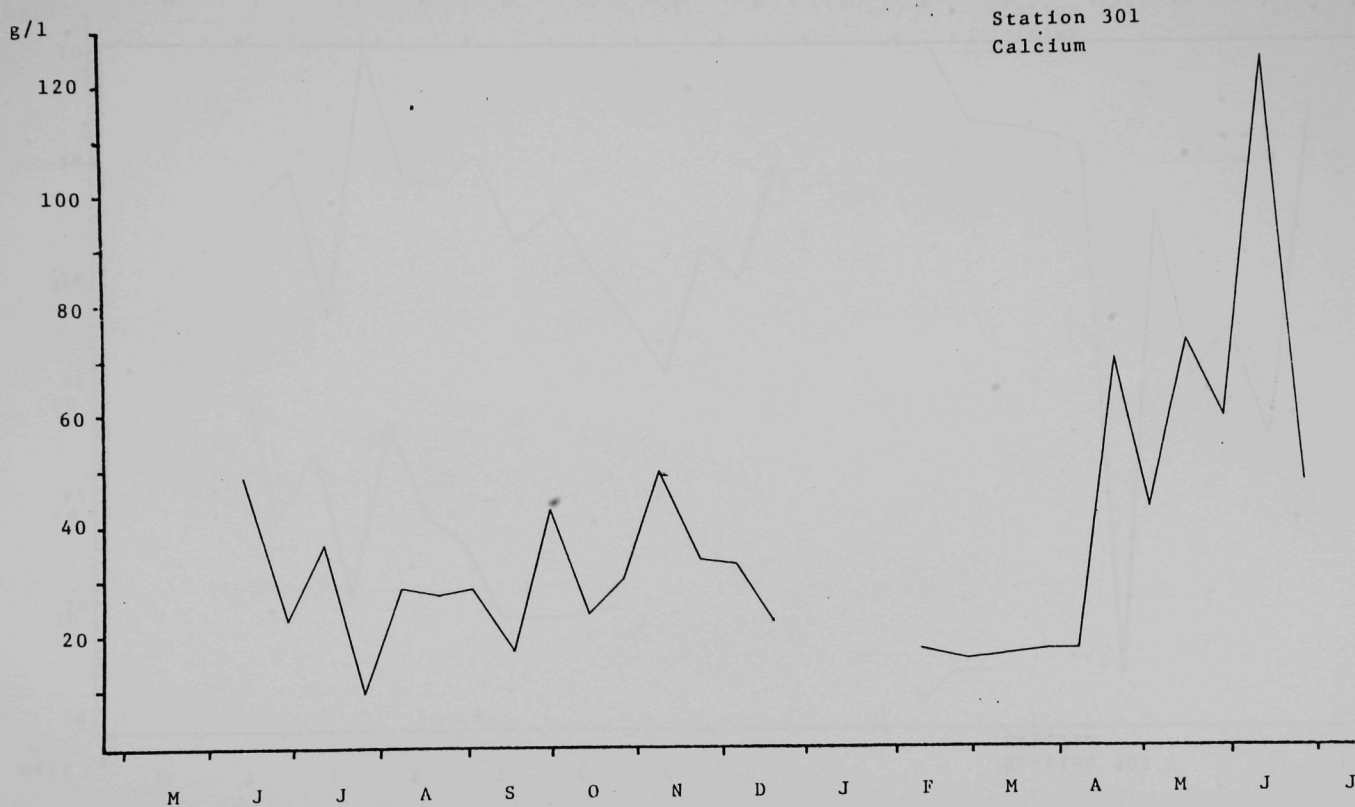
Station 306
Iron

173

mg/l

Station 307
Iron

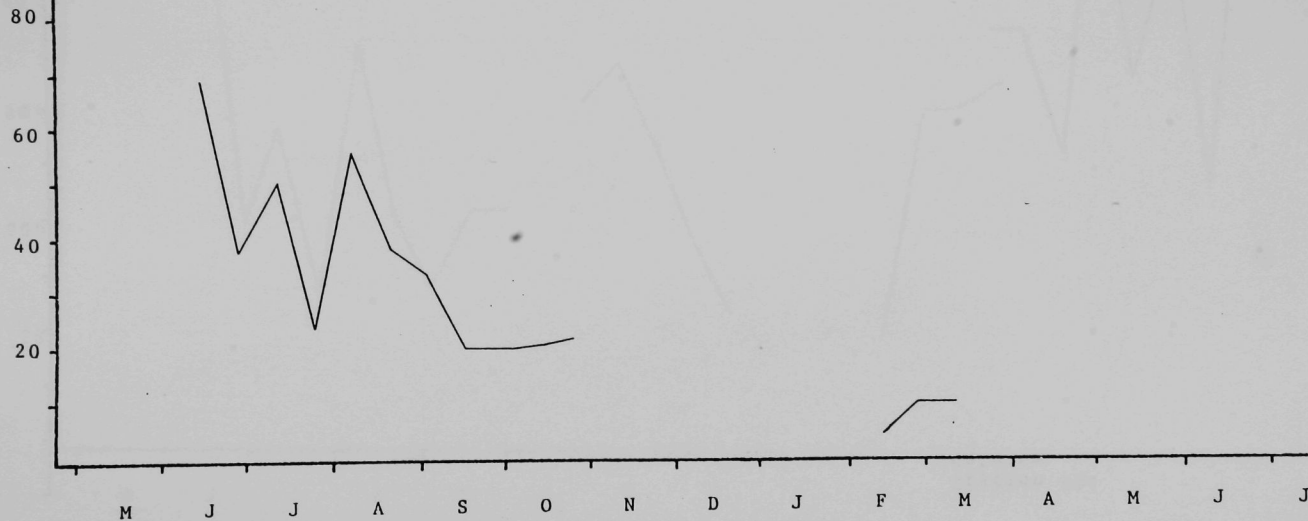






µg/l

Station 303
Calcium



mg/l

Station 304
Calcium

60

50

40

30

20

M

J

J

A

S

O

N

D

J

F

M

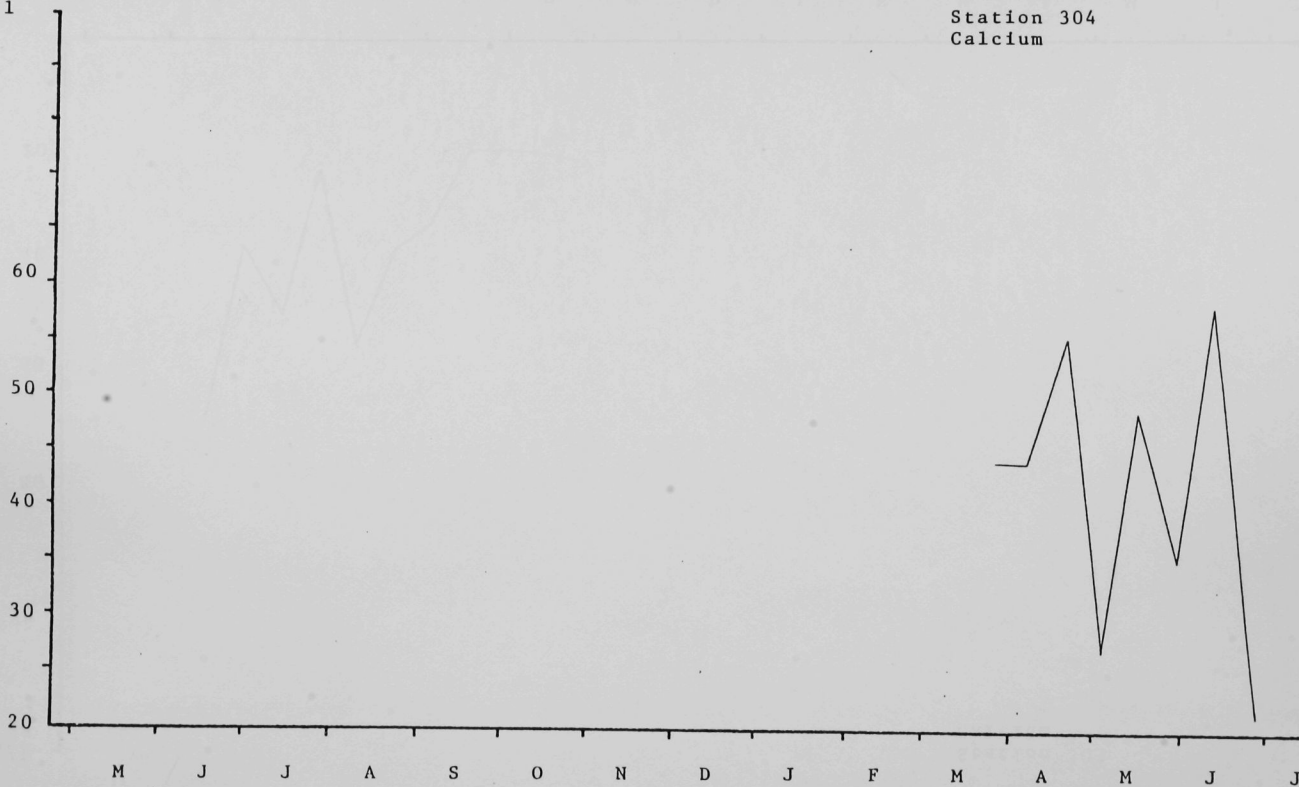
A

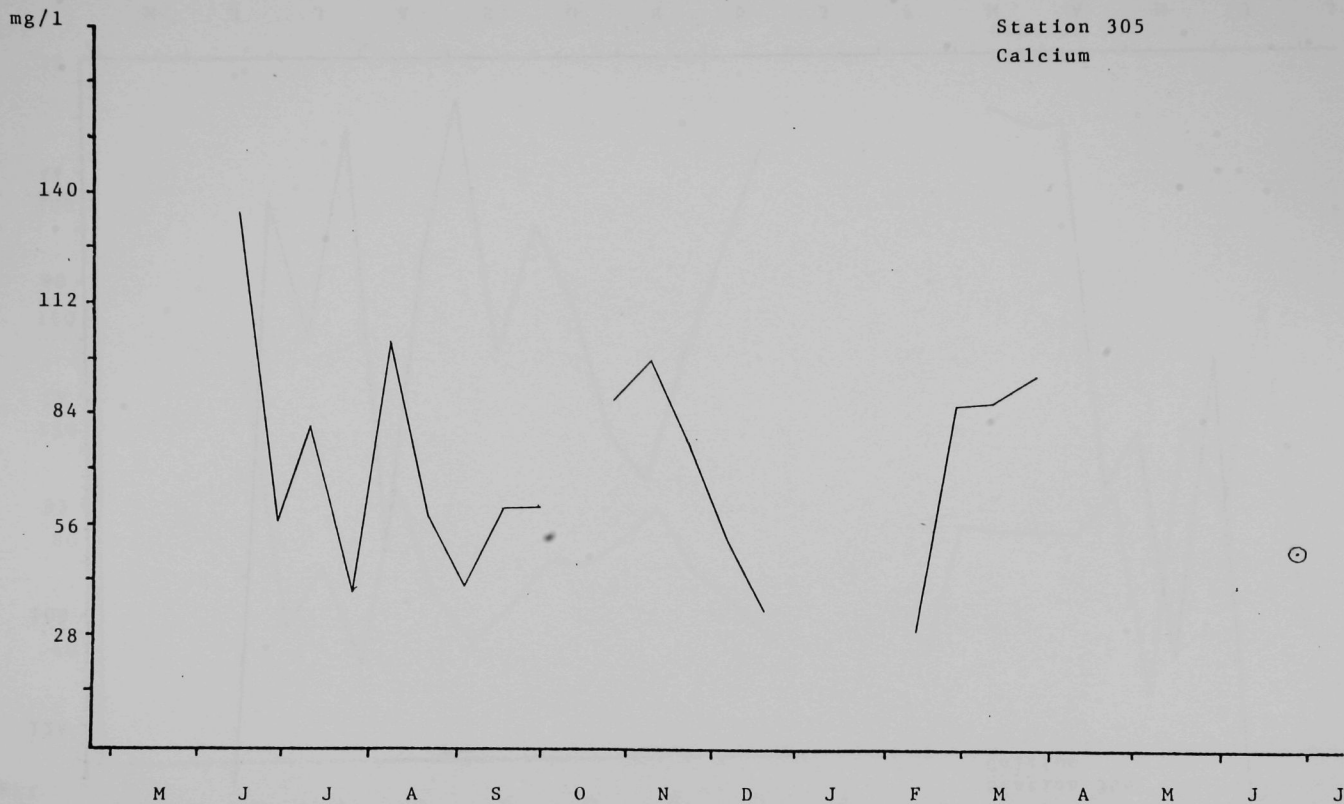
M

J

J

178





mg/l

Station 306
Calcium

124

108

92

76

60

44

28

M

J

J

A

S

O

N

D

J

F

M

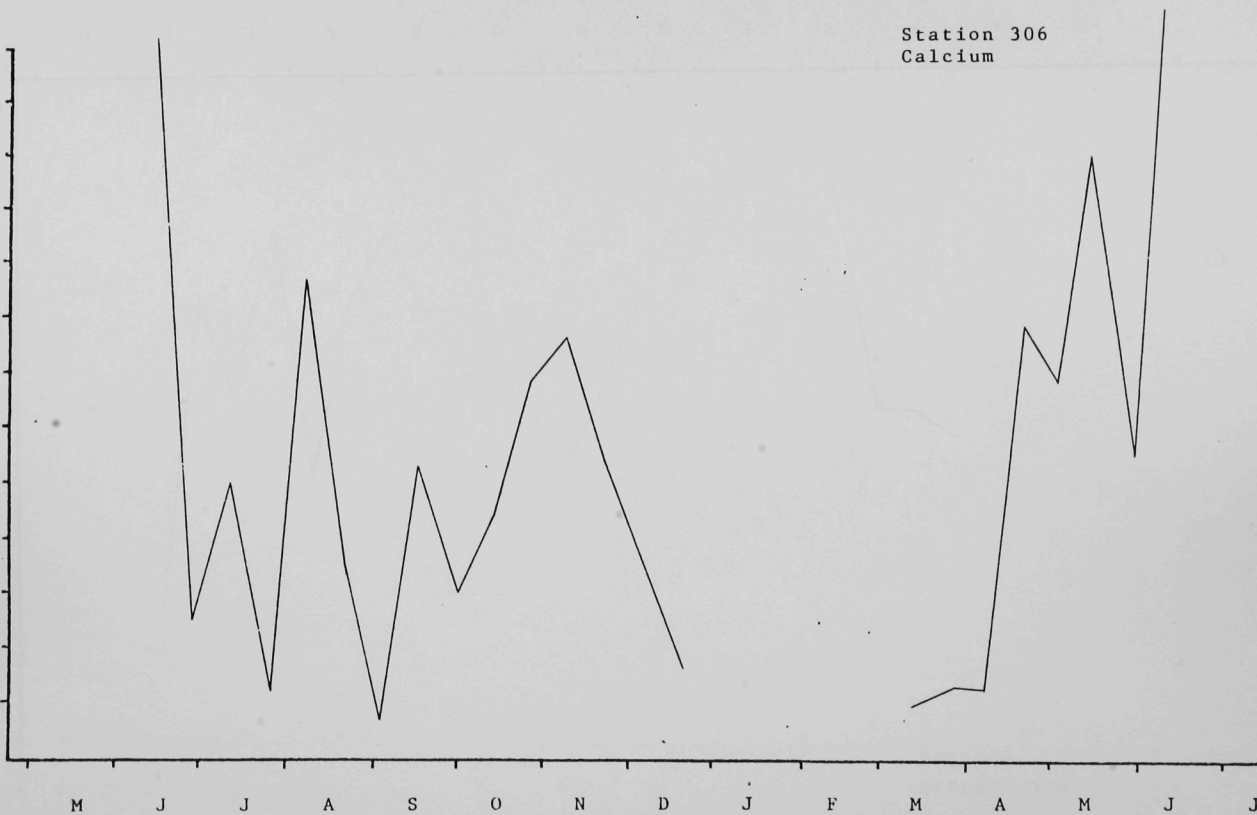
A

M

J

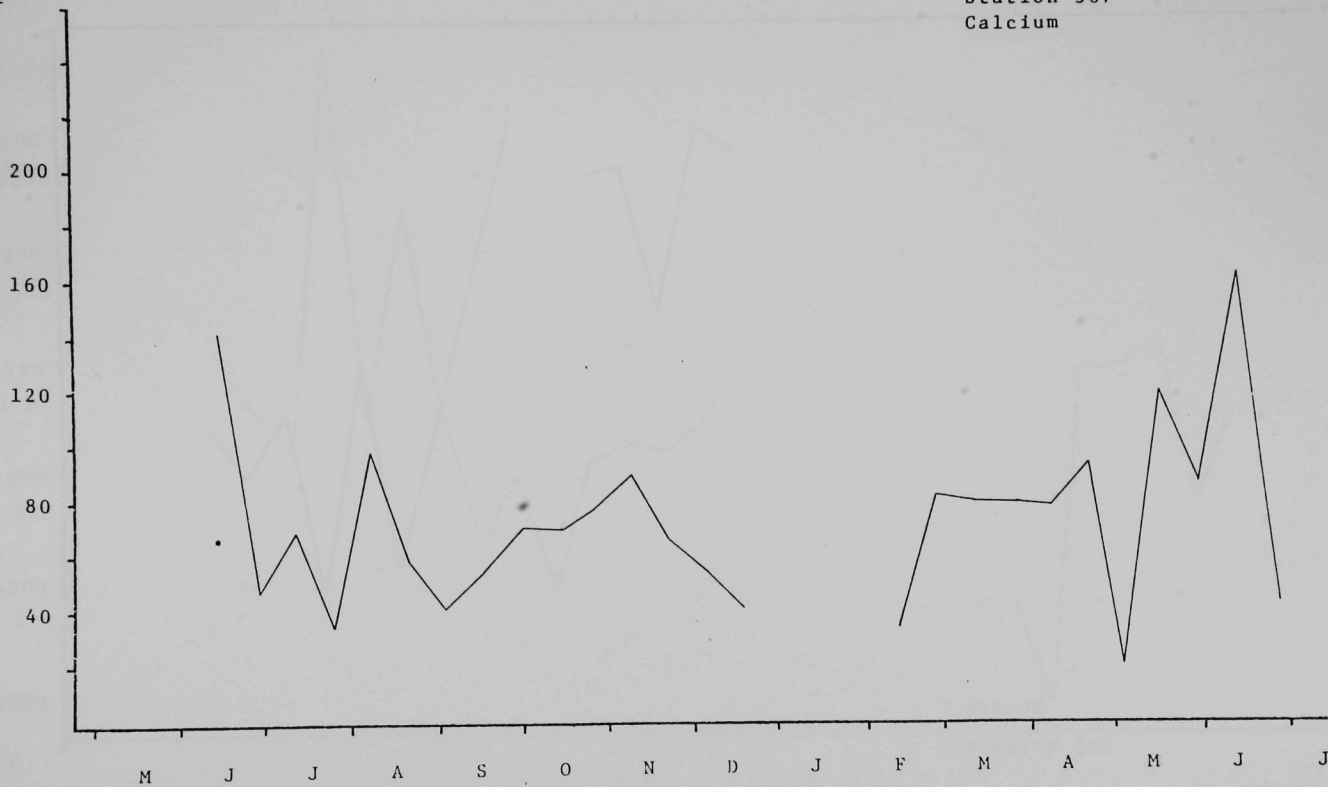
J

180



/1

Station 307
Calcium



181

mg/l

Station 305

Sodium

2400

2000

1600

1200

800

400

M

J

J

A

S

O

N

D

J

F

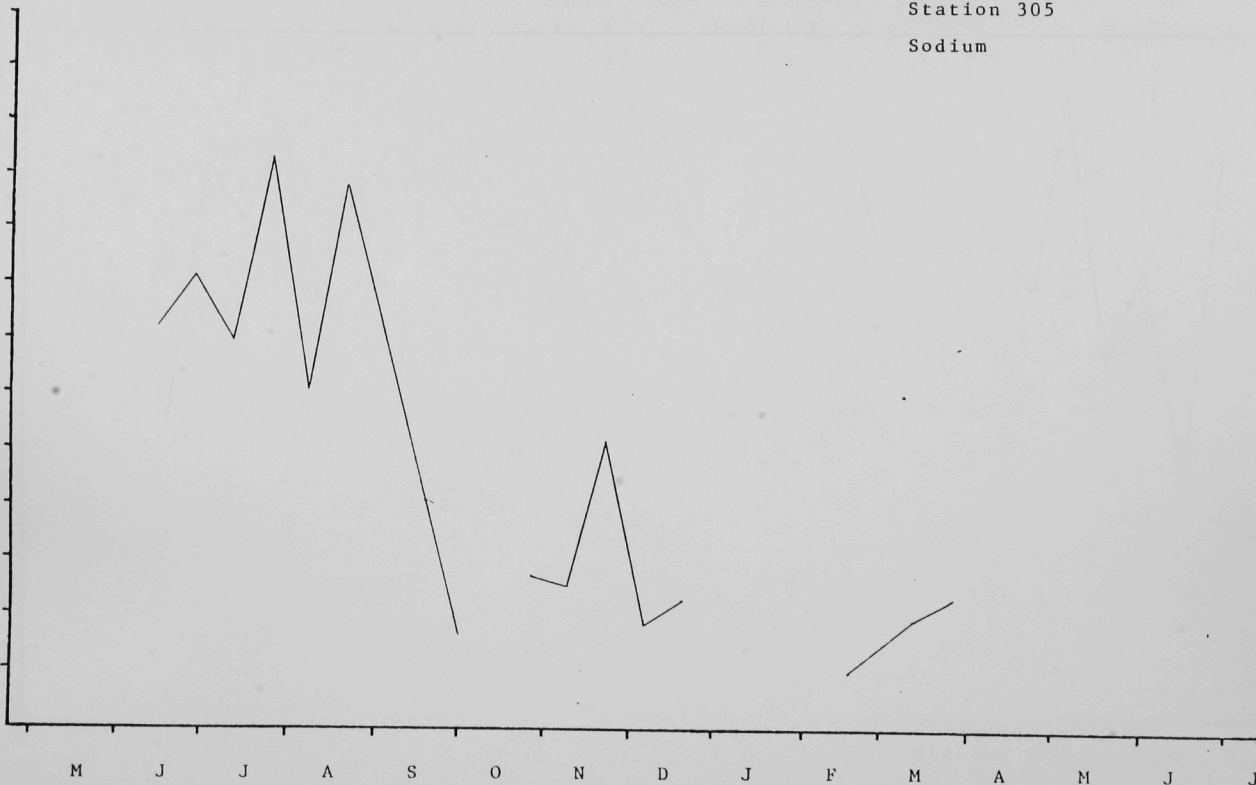
M

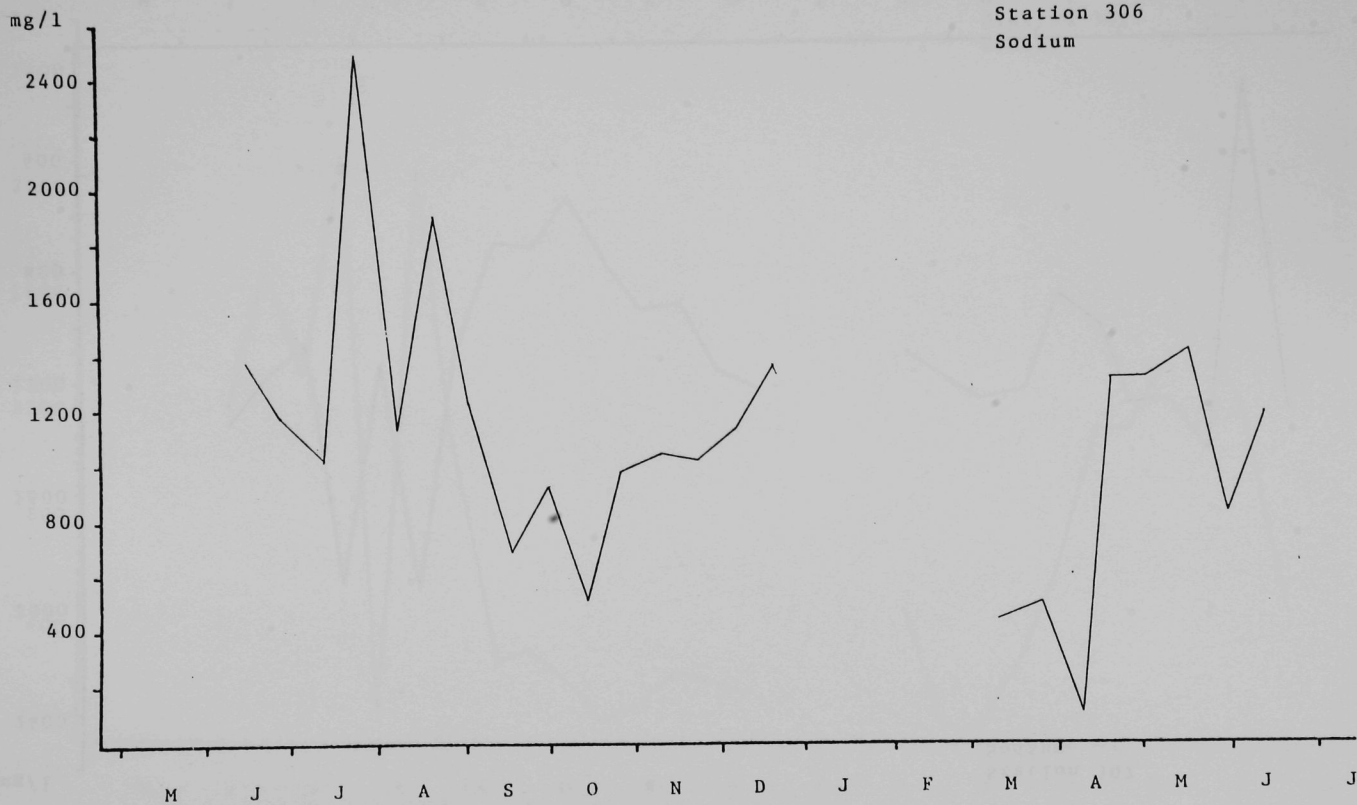
A

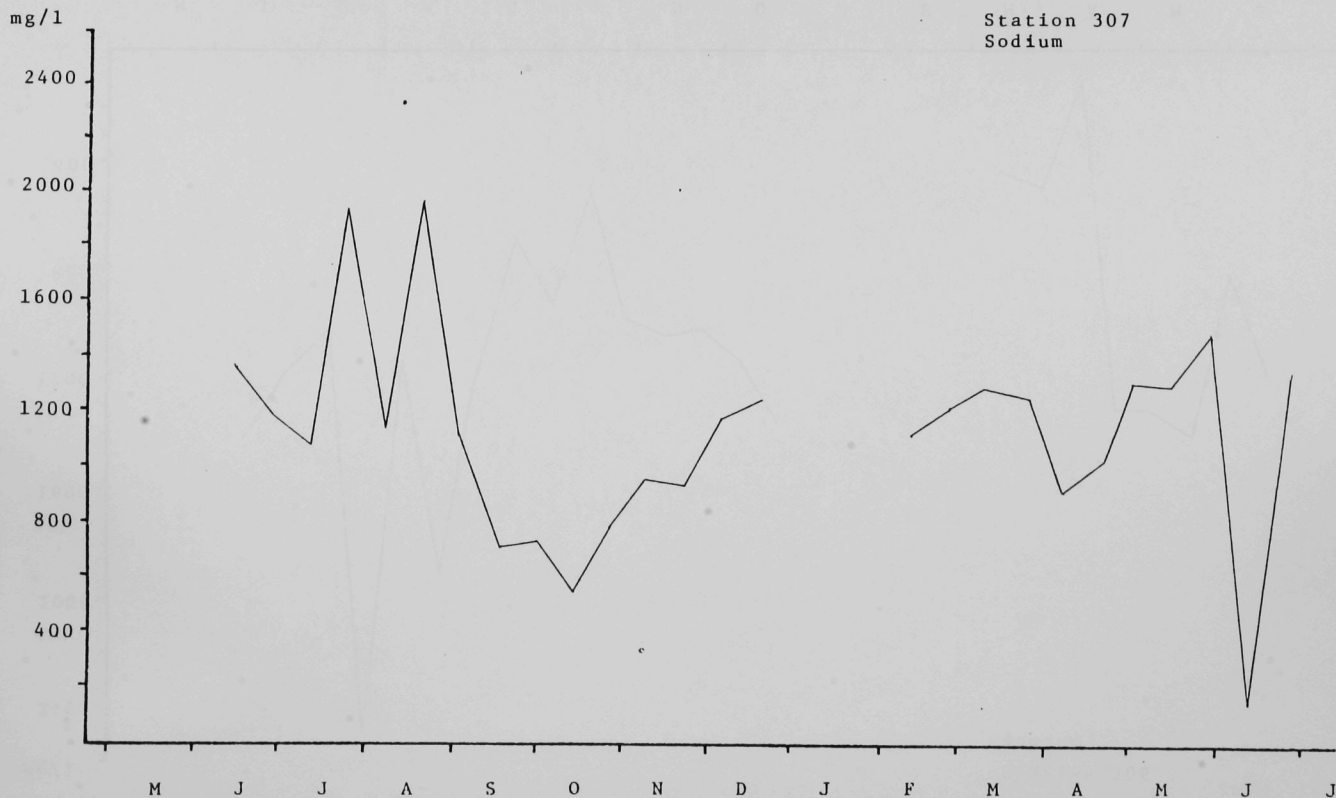
M

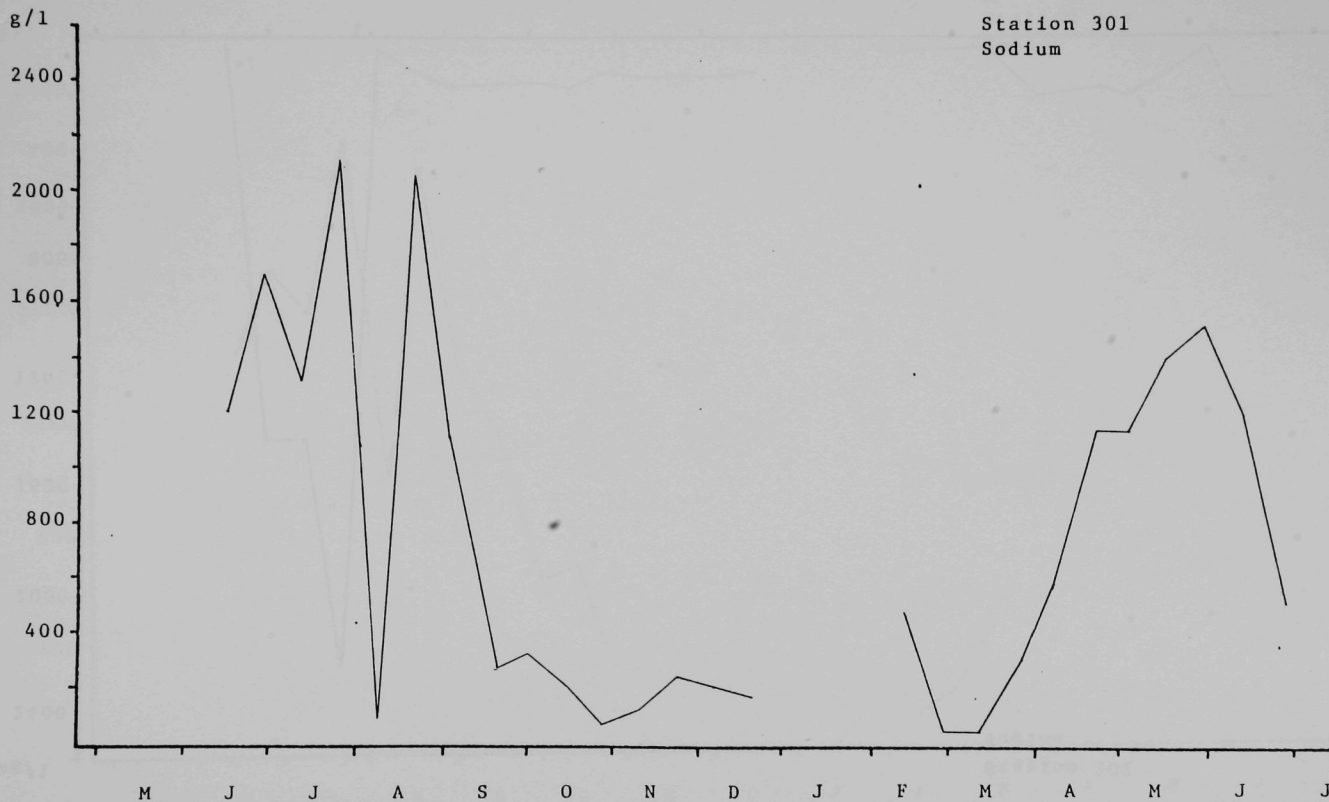
J

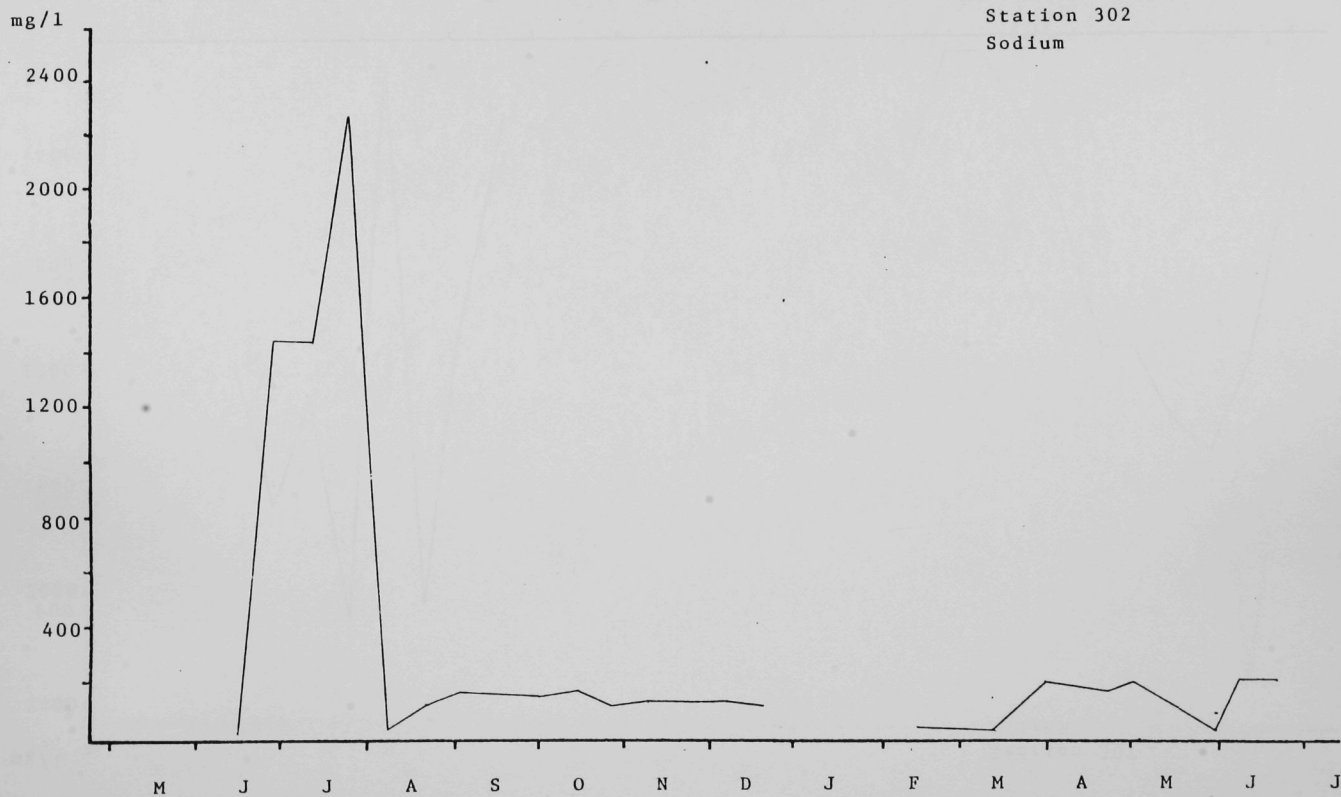
J

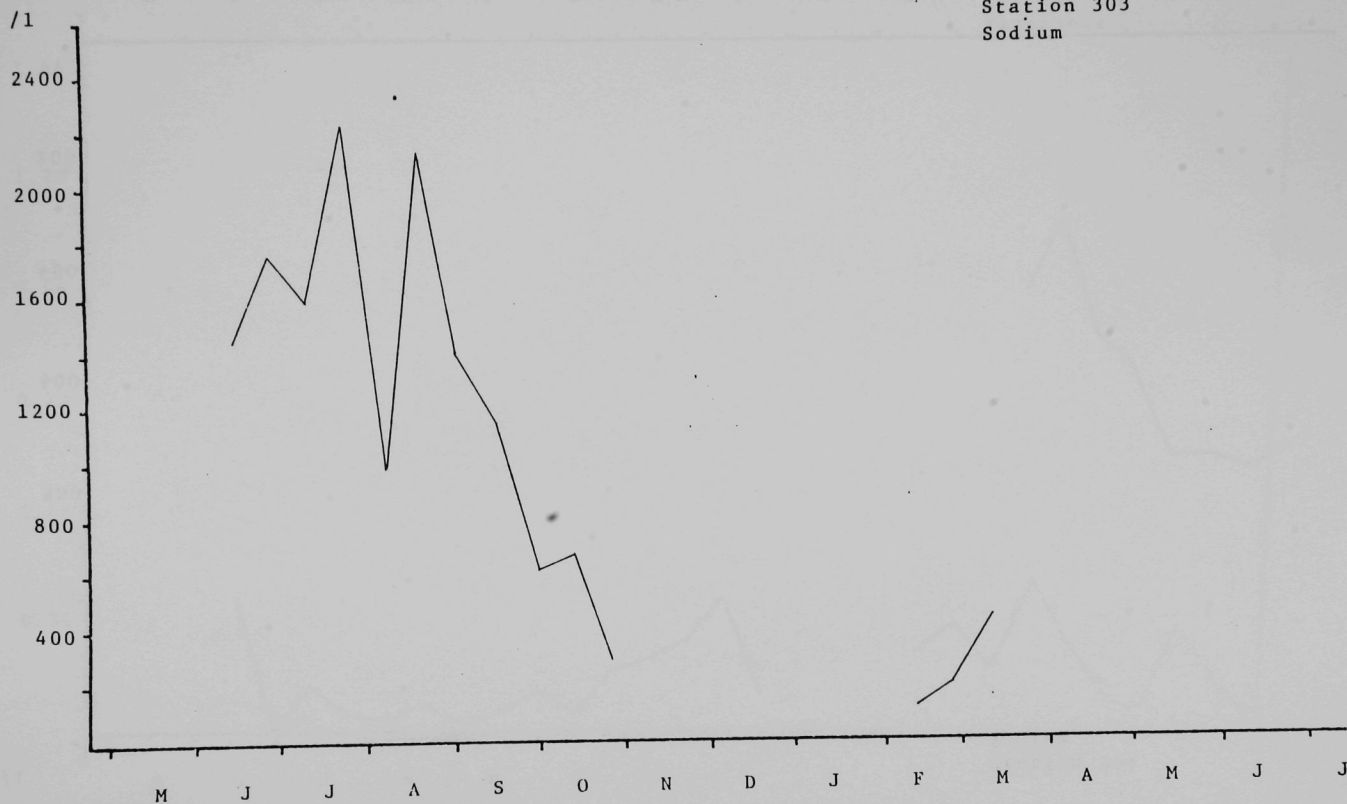






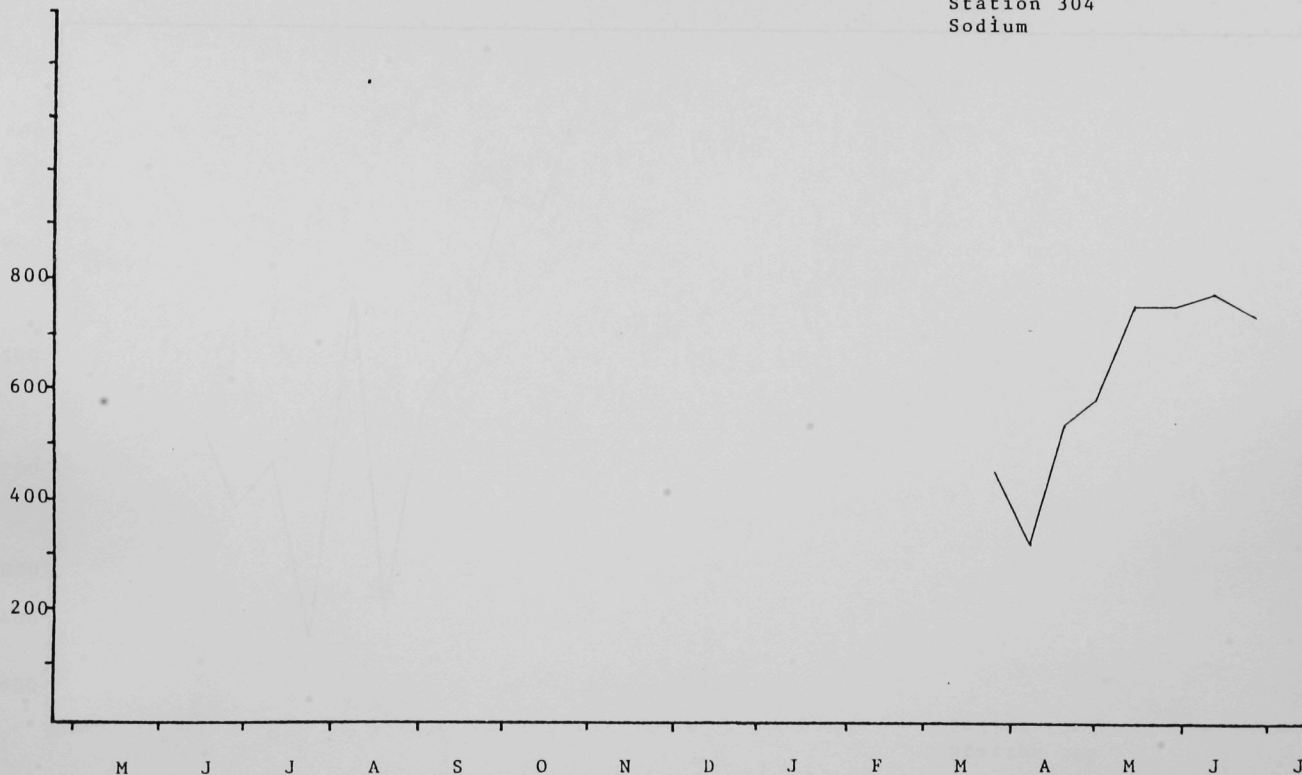


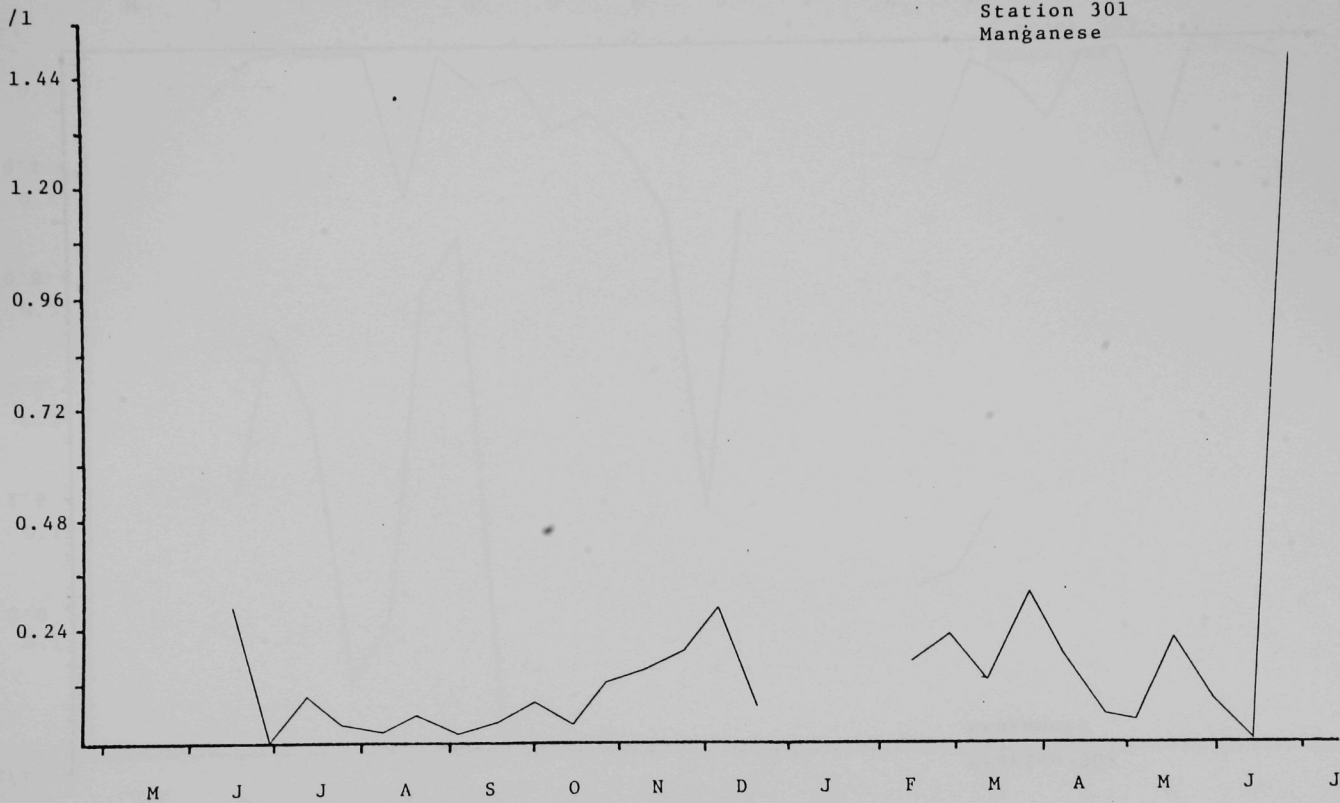




Station 304
Sodium

mg/l





mg/l

Station 302

Manganese

2.0

1.6

1.2

0.8

0.4

M

J

J

A

S

O

N

D

J

F

M

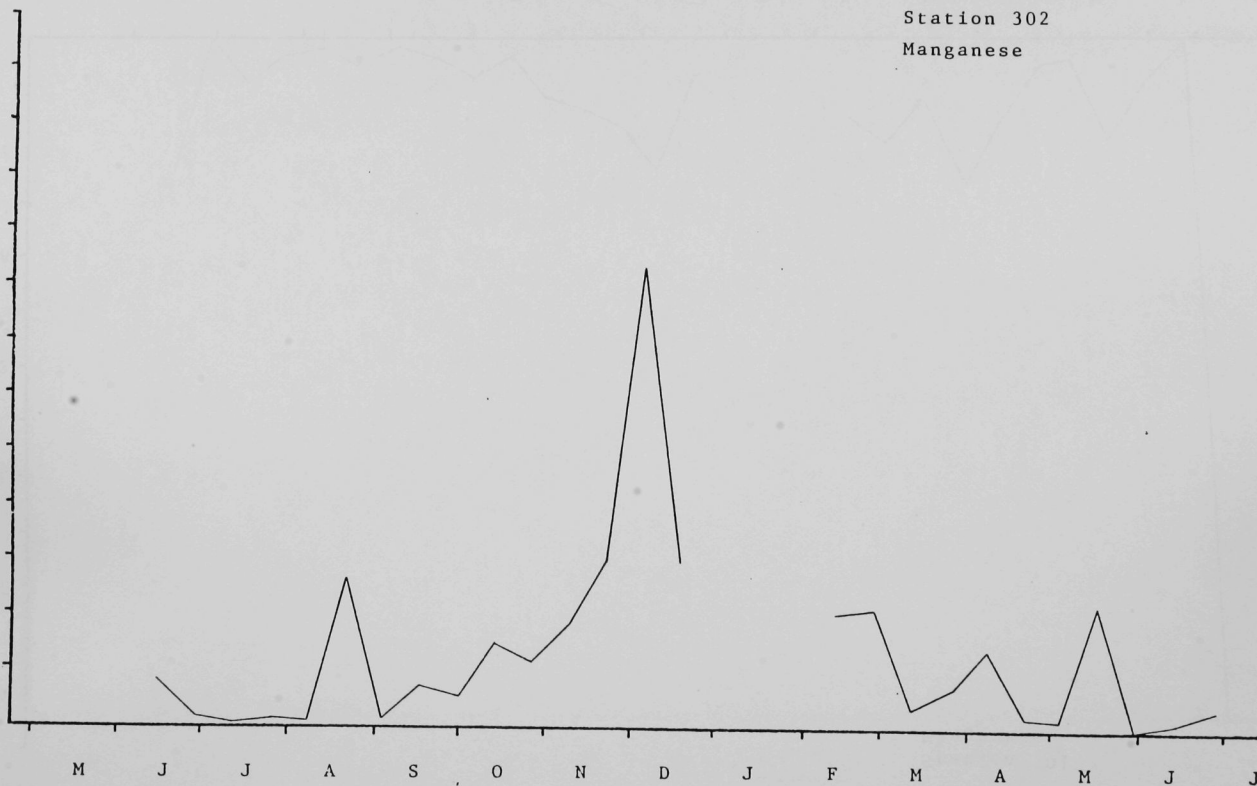
A

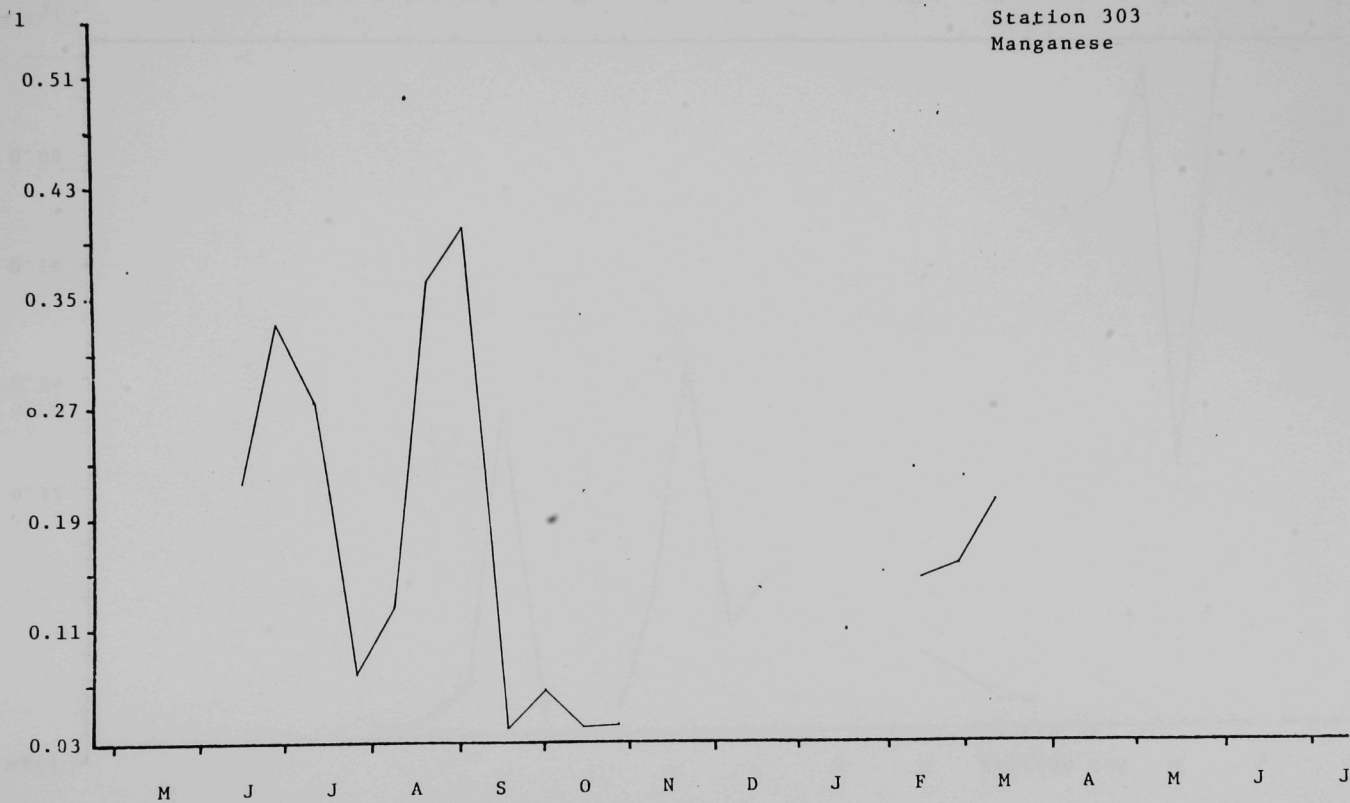
M

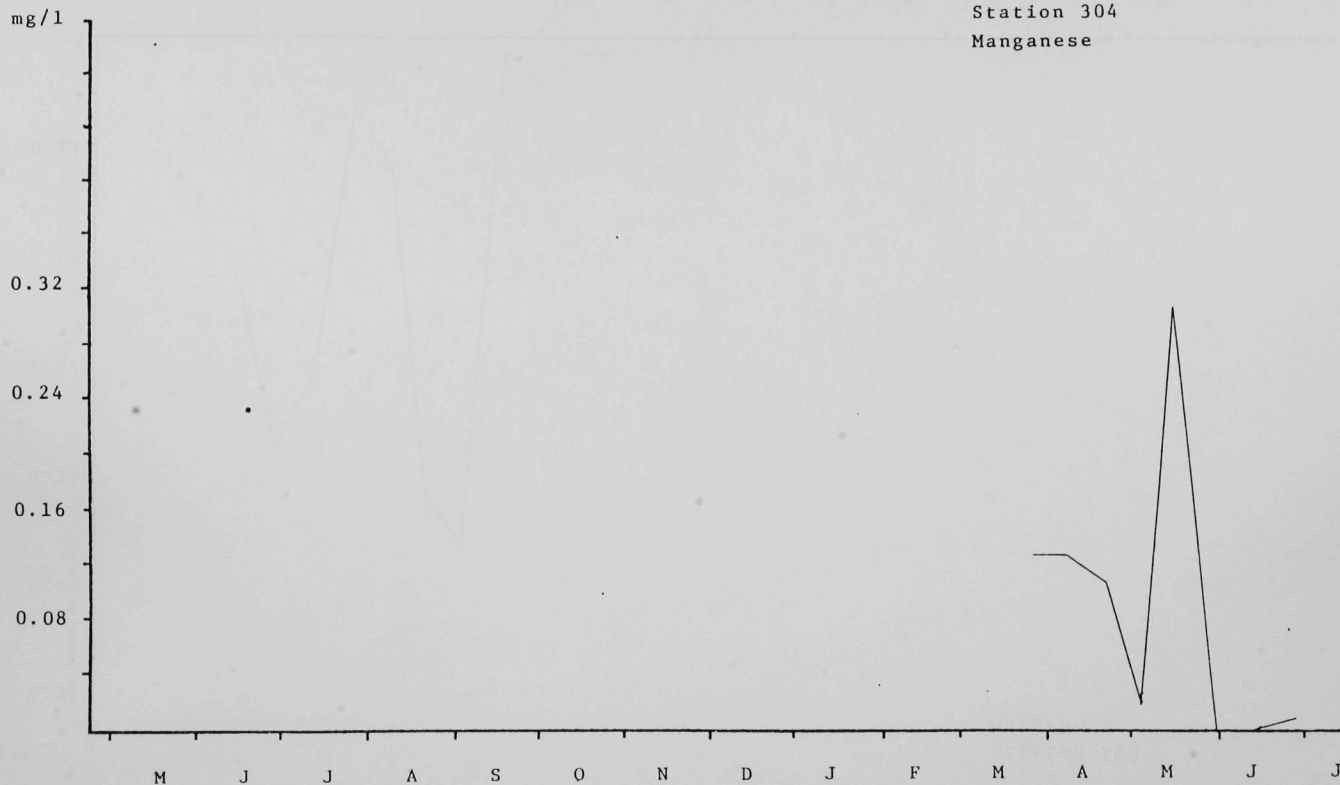
J

J

190







mg/l

Station 305
Manganese

2.4

1.8

1.2

0.6

M

J

J

A

S

O

N

D

J

F

M

A

M

J

J

193

○

mg/l

Station 306
Manganese

0.78

0.66

0.54

0.42

0.30

0.18

0.06

M

J

J

A

S

O

N

D

J

F

M

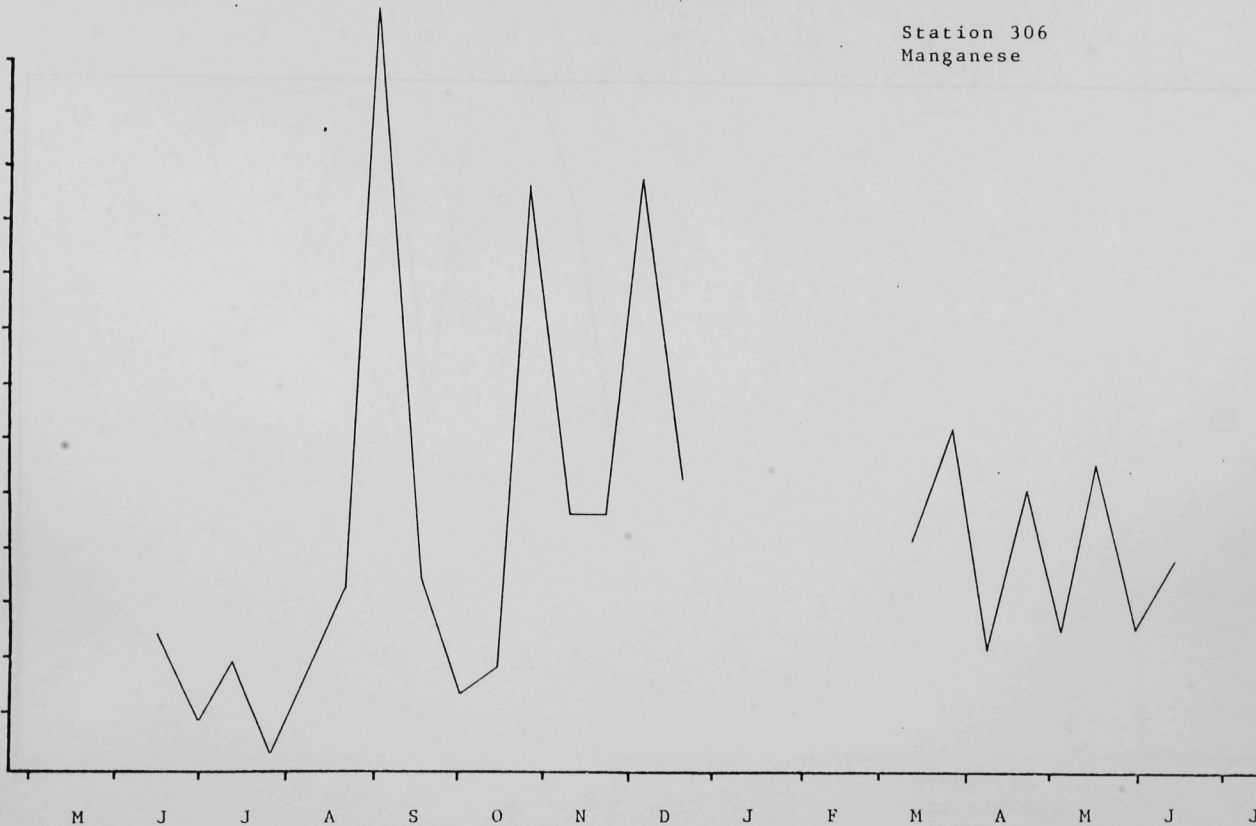
A

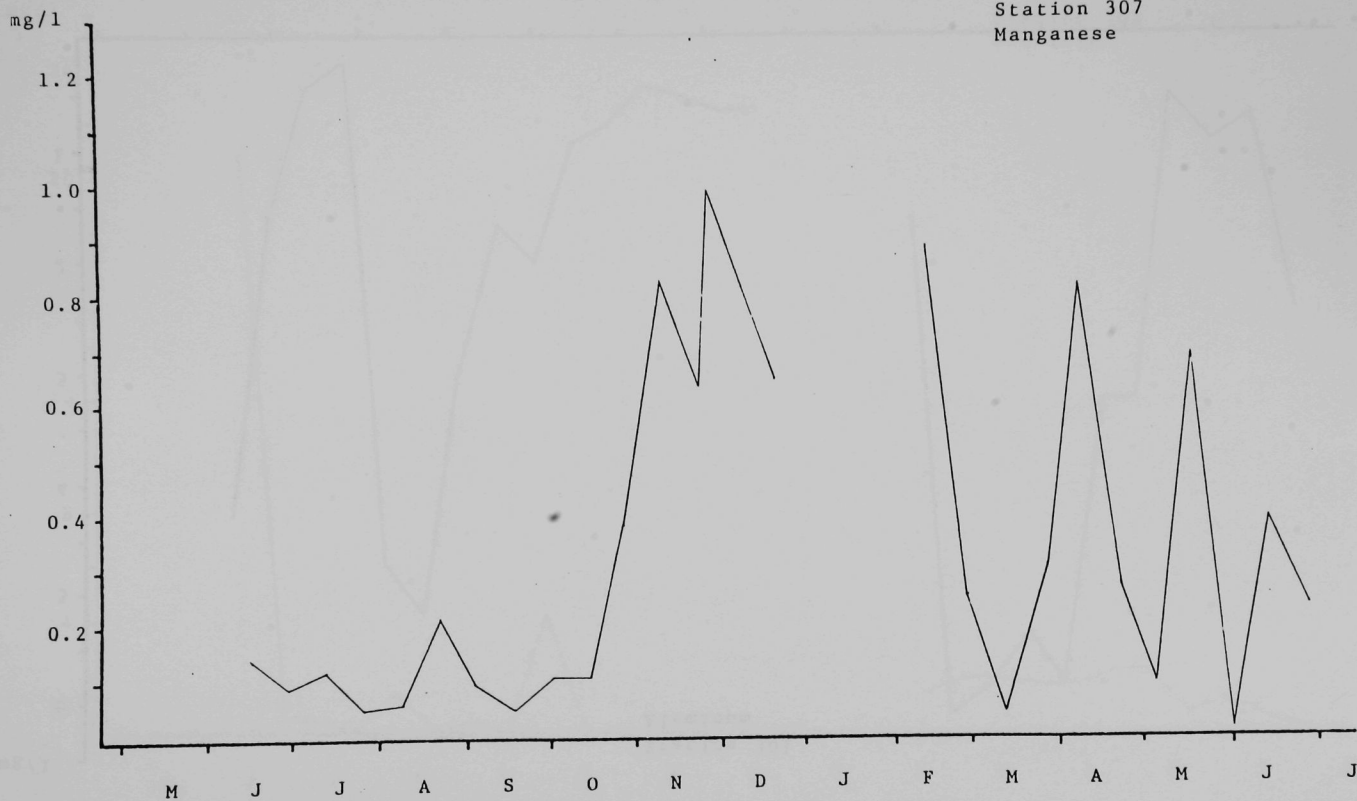
M

J

J

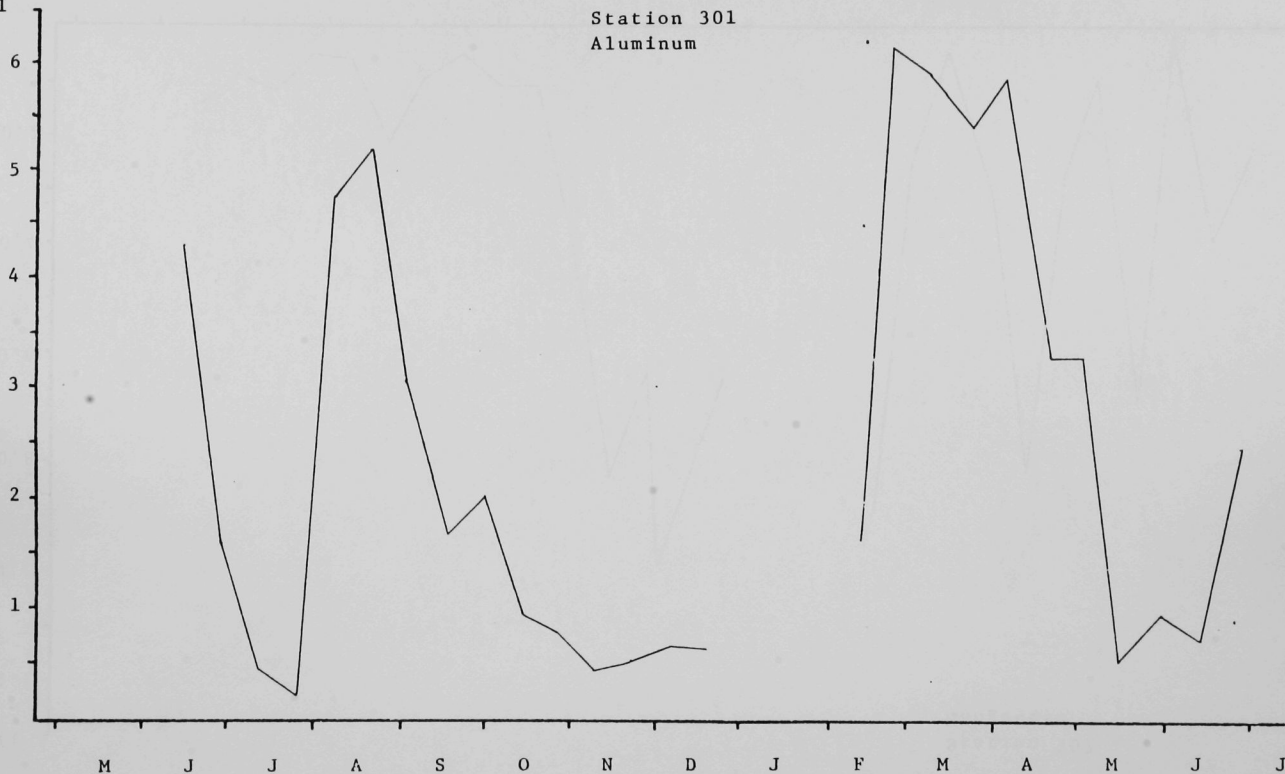
194

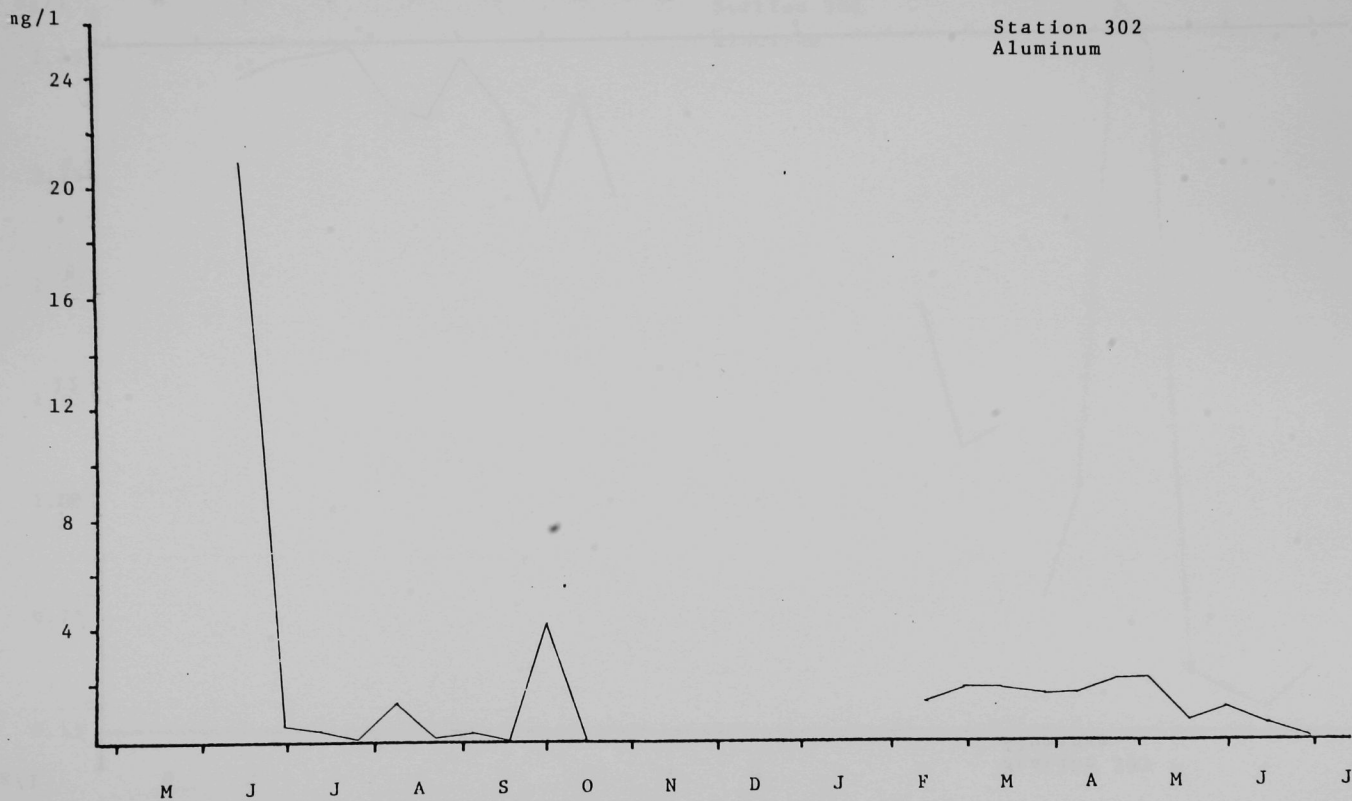




mg/l

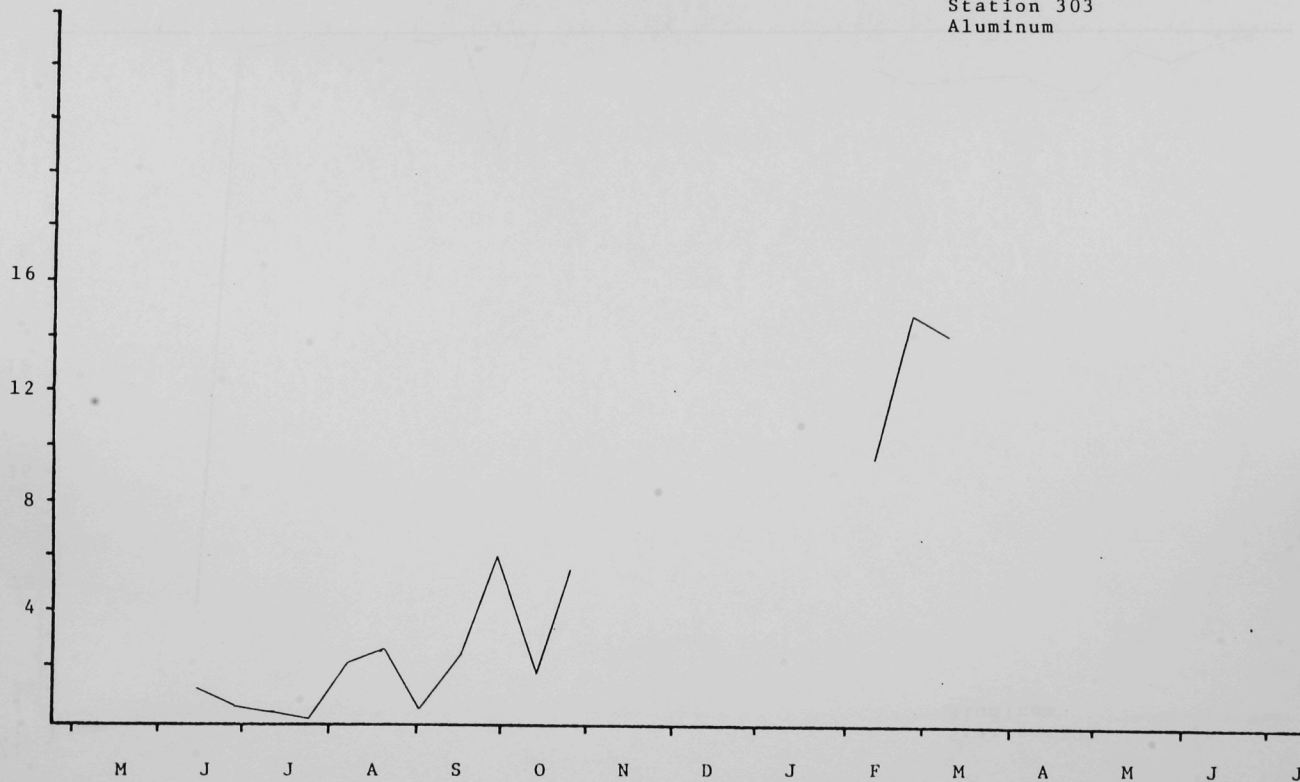
Station 301
Aluminum

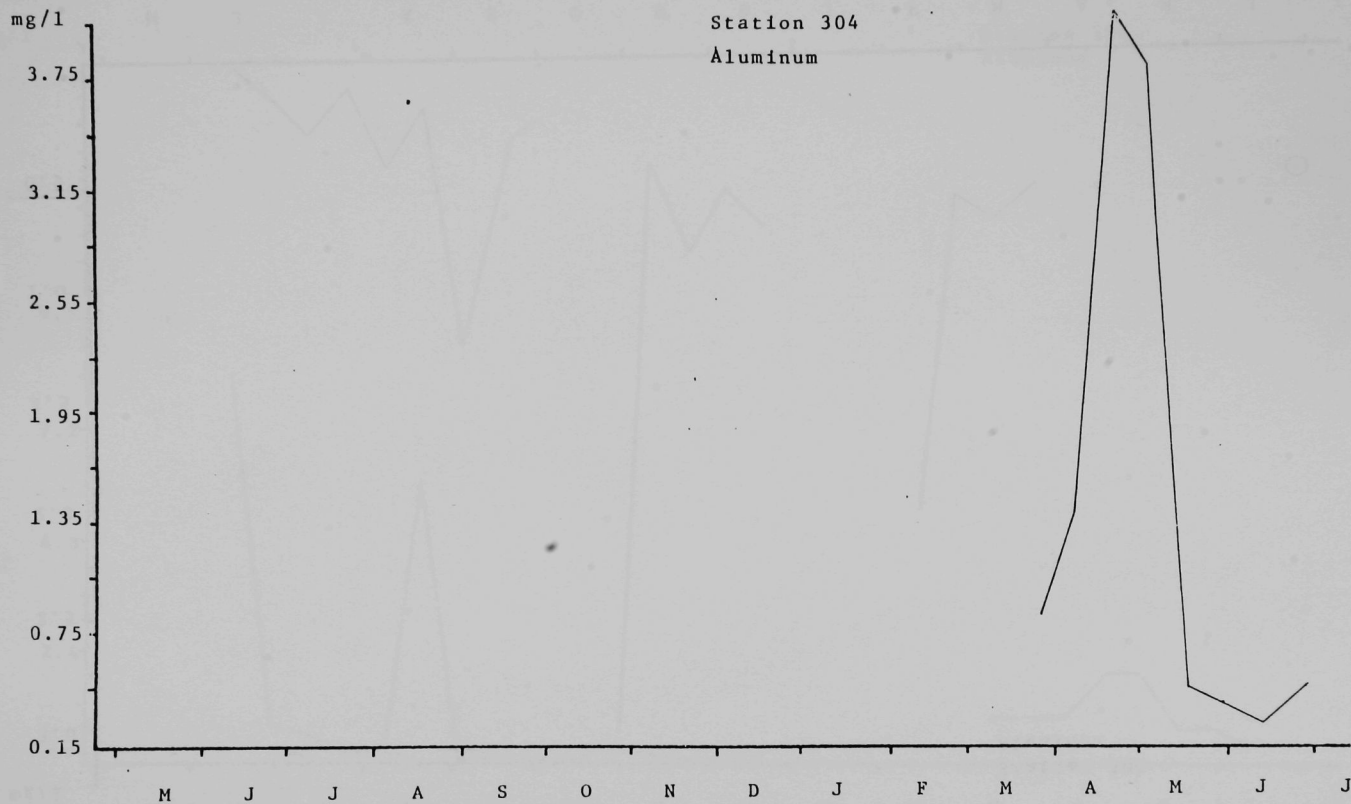


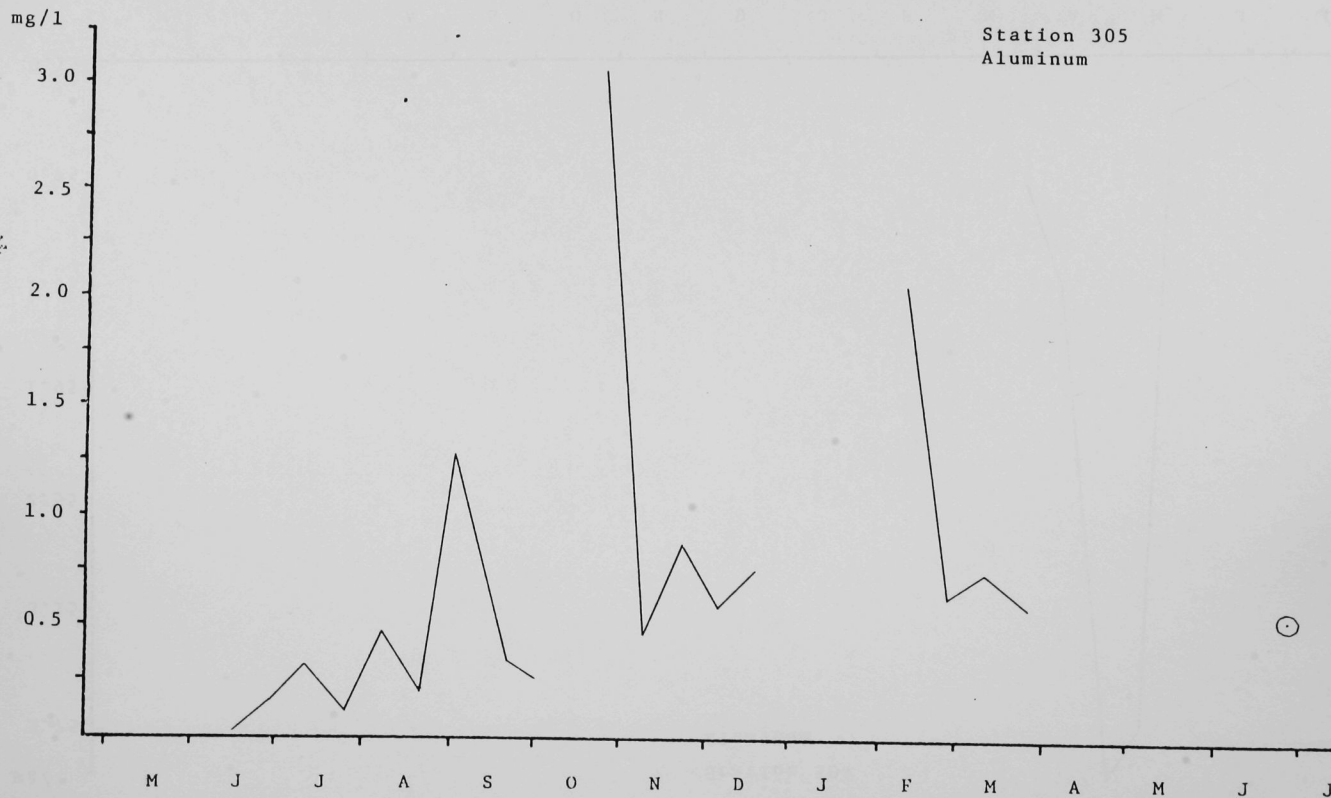


mg/l

Station 303
Aluminum

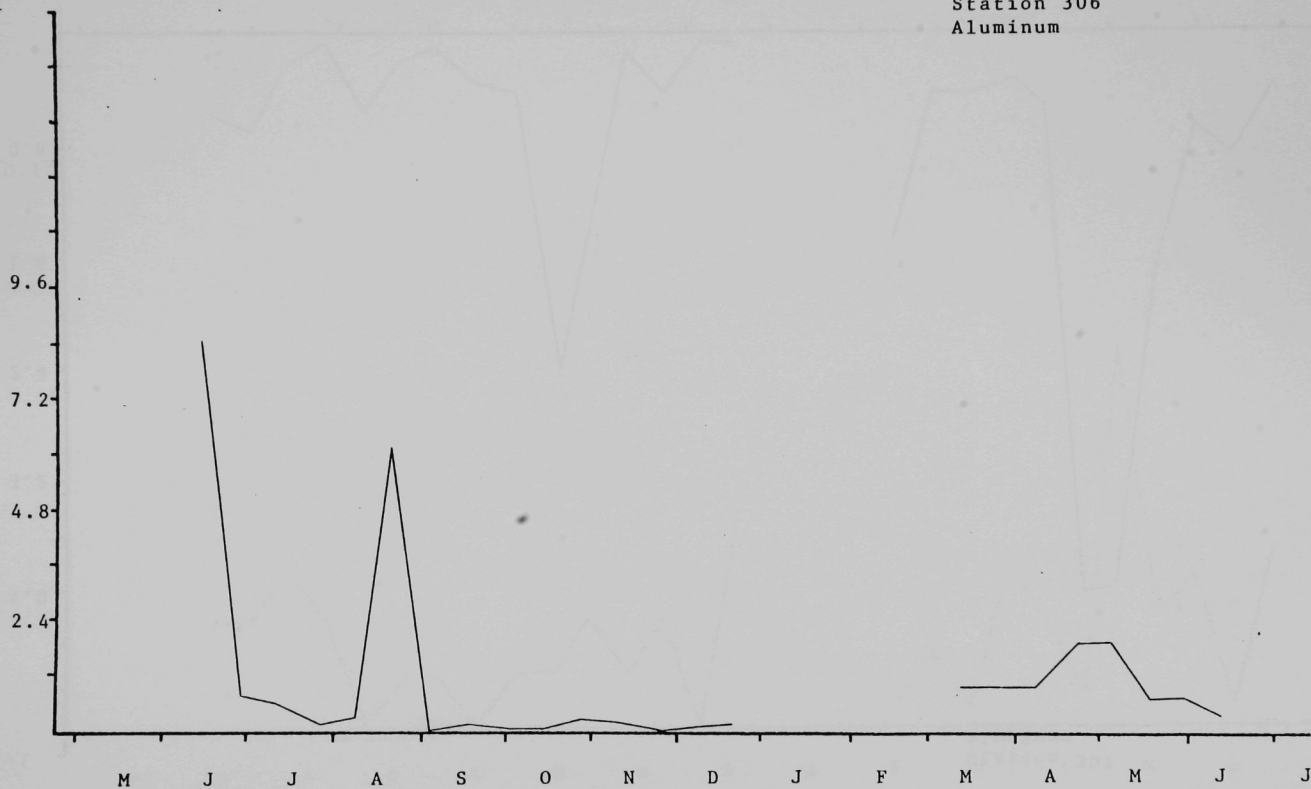






/1

Station 306
Aluminum



mg/l

Station 307
Aluminum

4.0

3.2

2.4

1.6

0.8

M

J

J

A

S

O

N

D

J

F

M

A

M

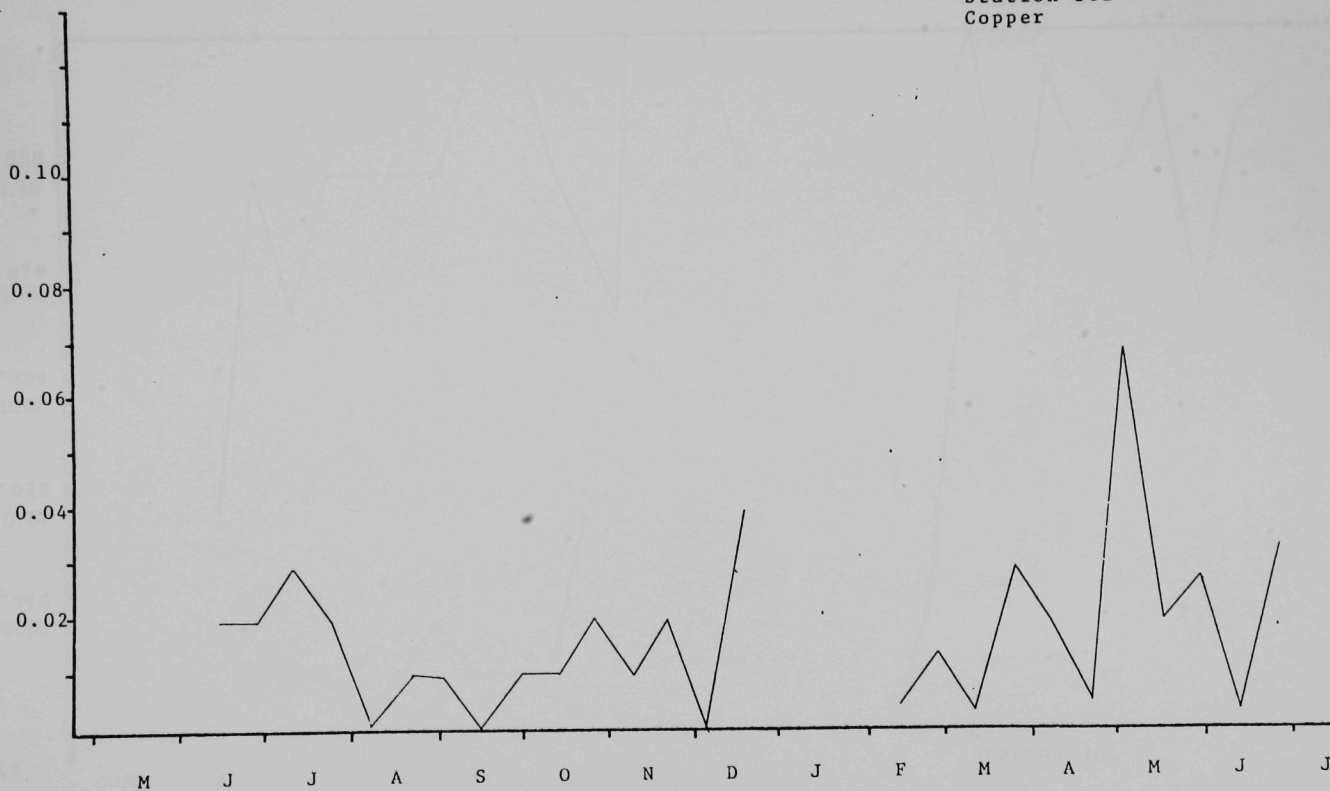
J

J

202



Station 301
Copper



mg/l

Station 302
Copper

.040

.032

.024

.016

.008

M

J

J

A

S

O

N

D

J

F

M

A

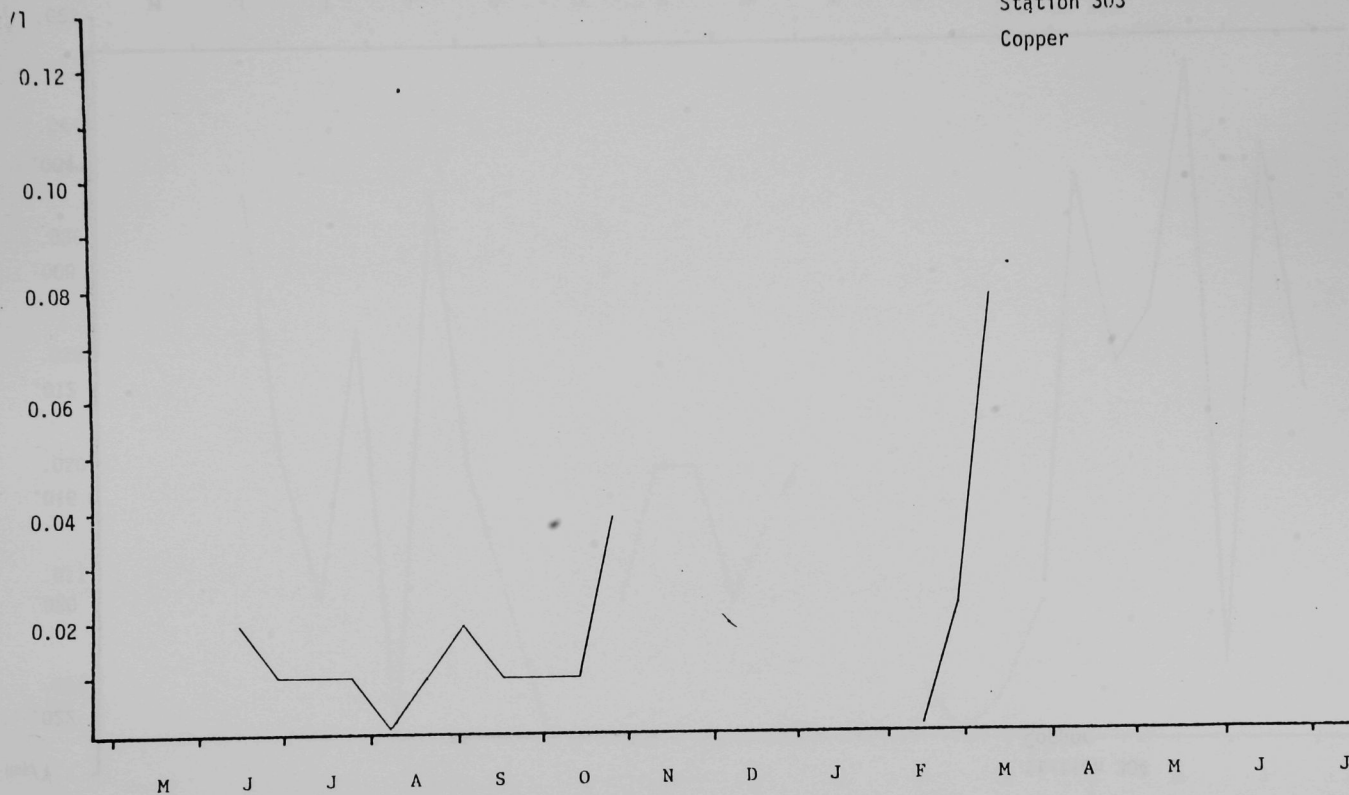
M

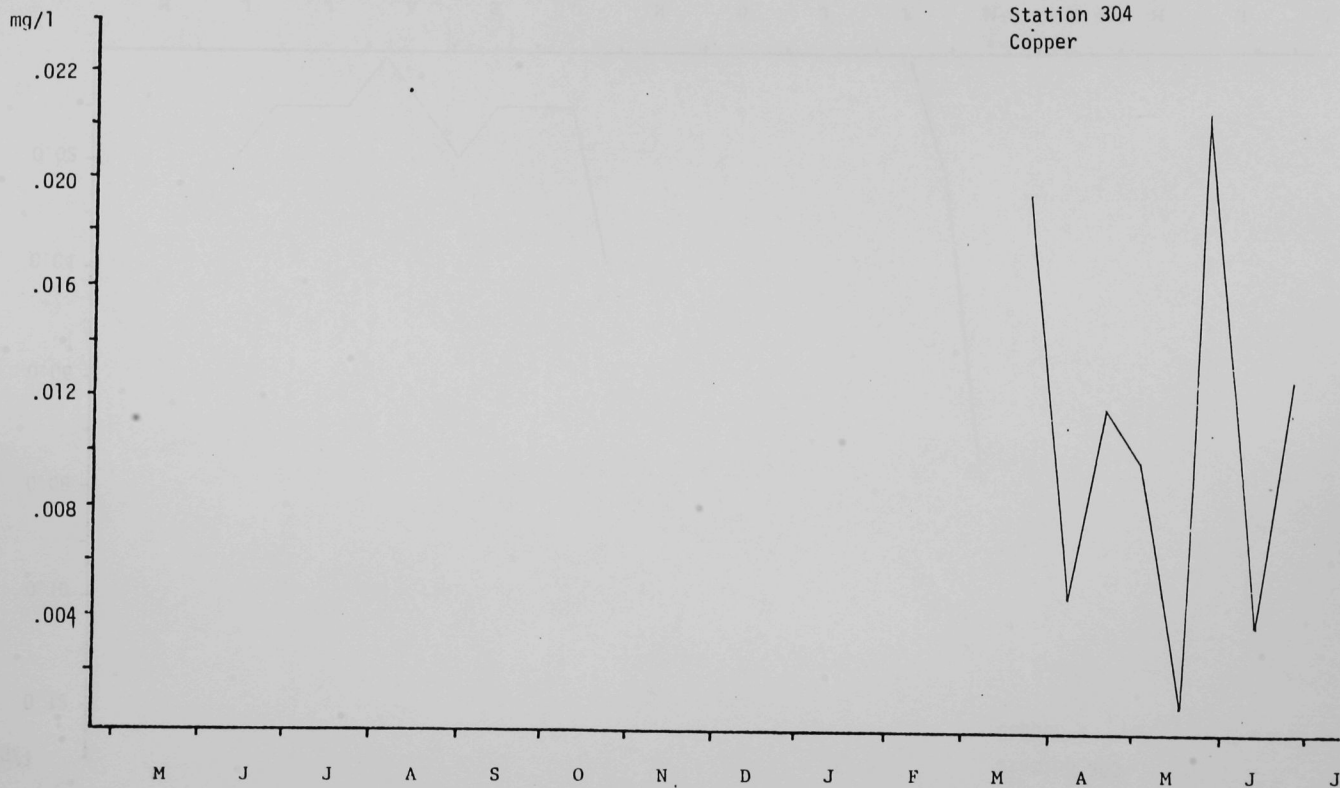
J

J

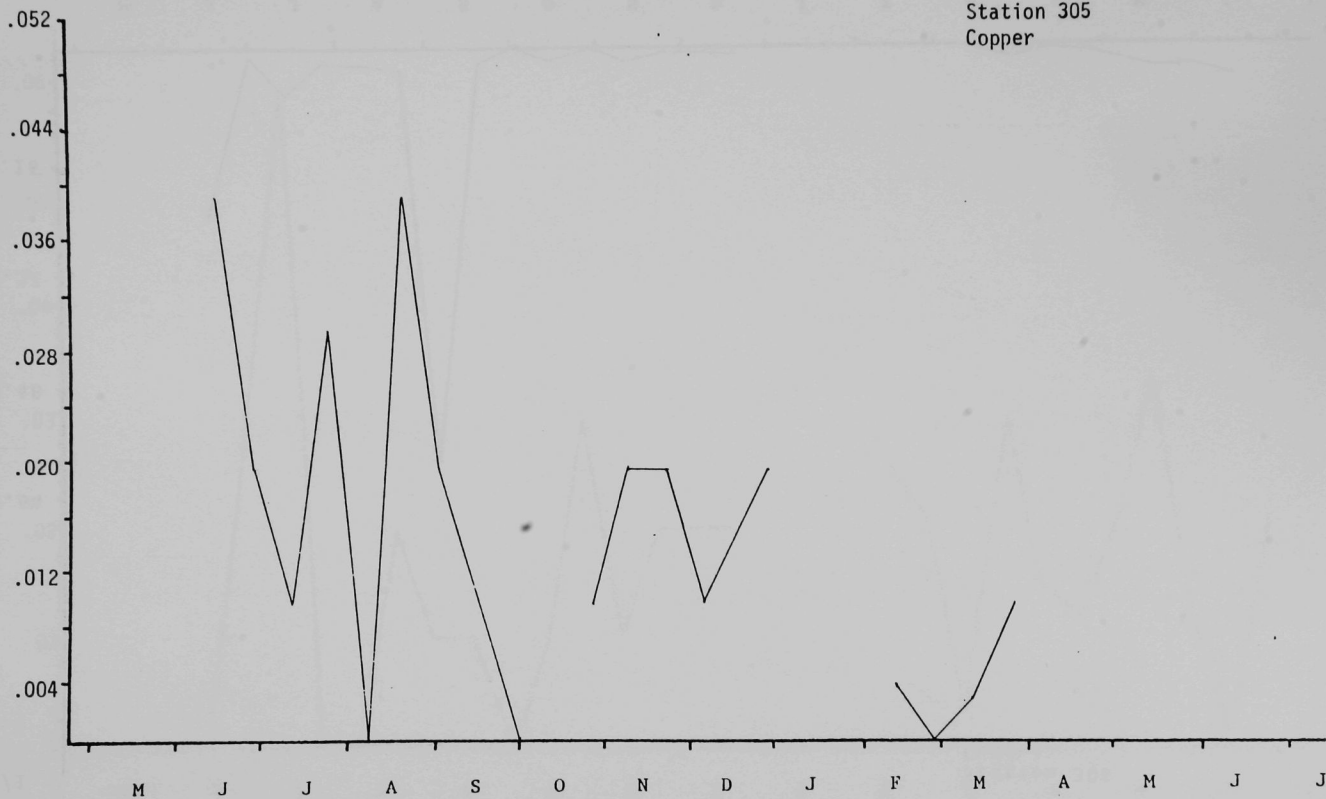
Station 303

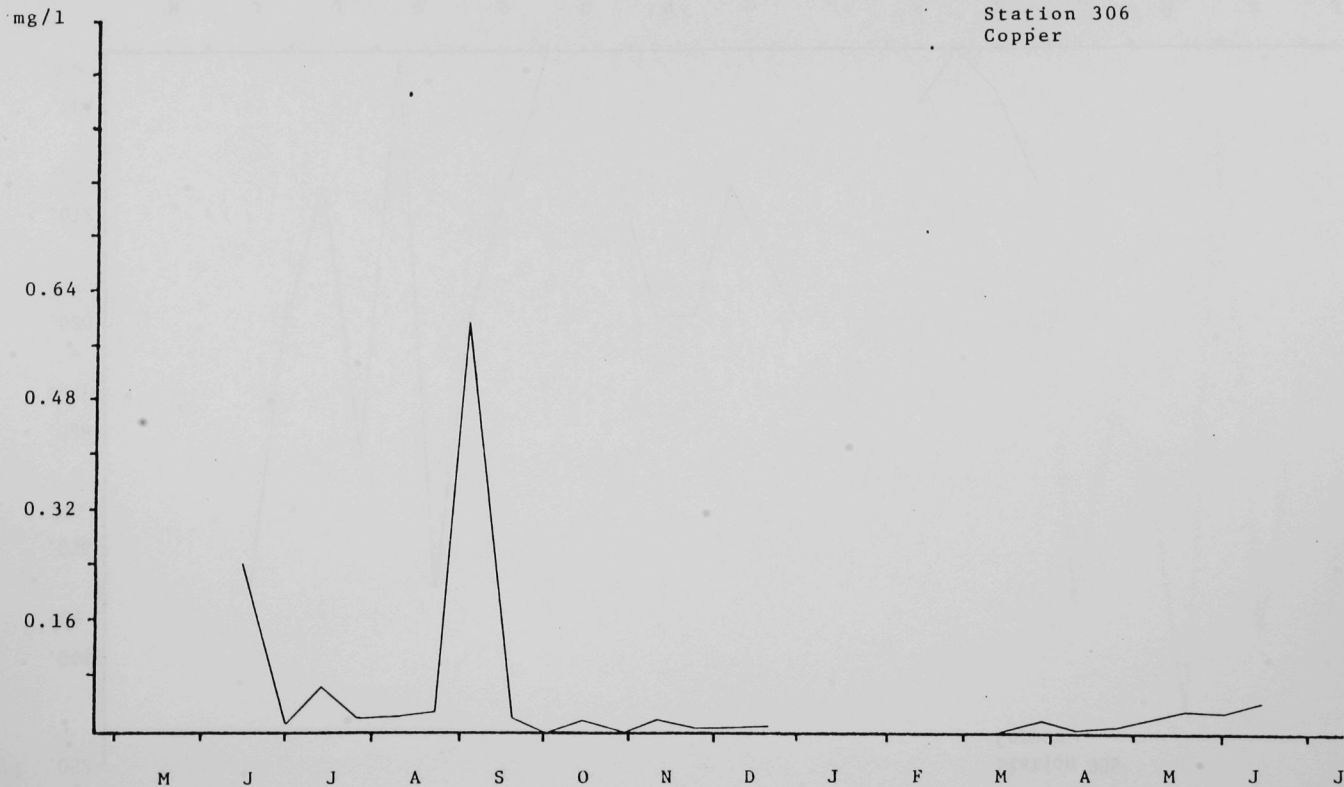
Copper



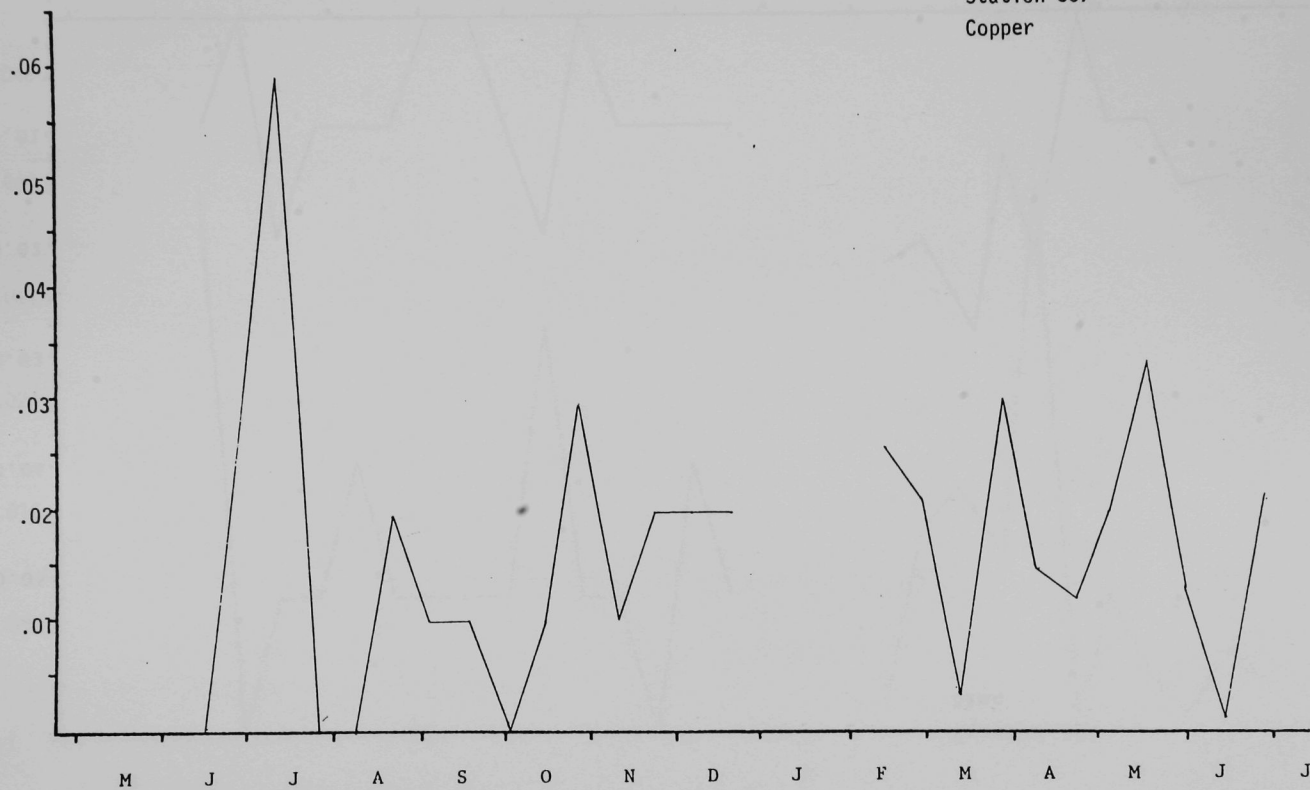


Station 305
Copper





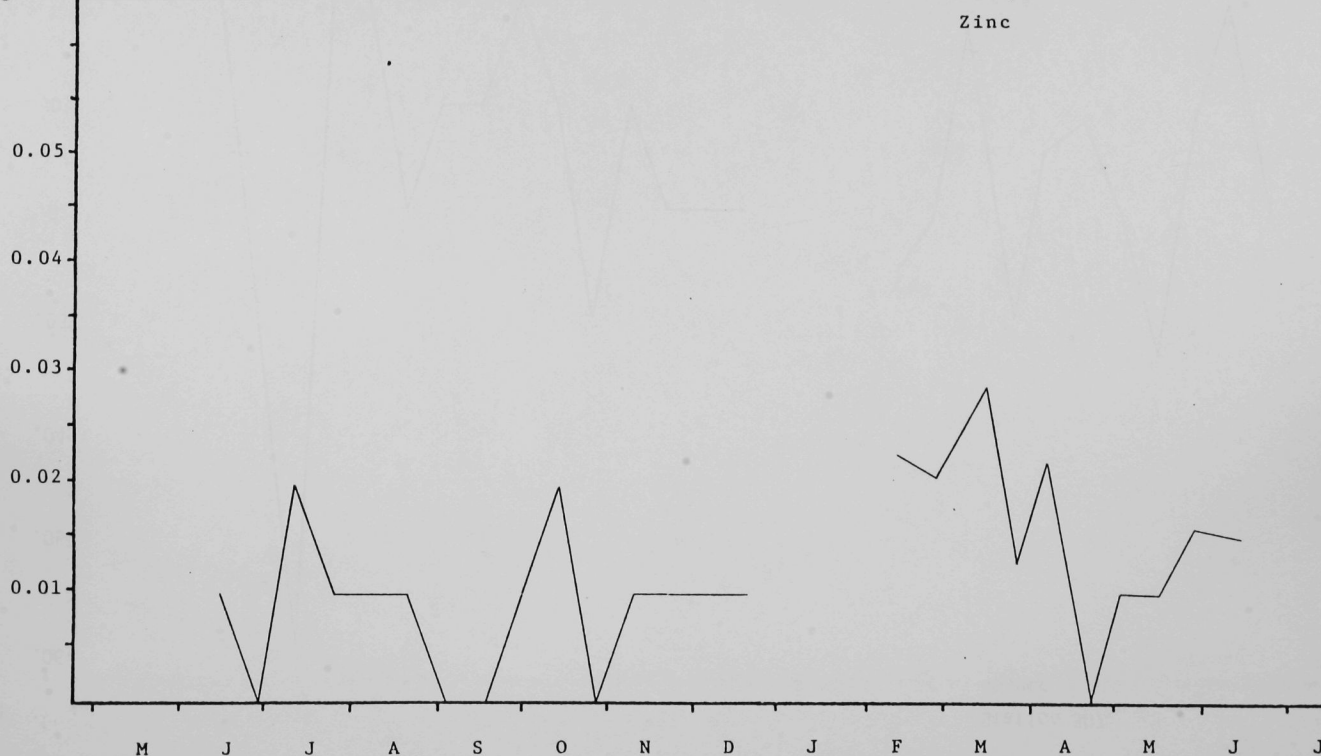
Station 307
Copper



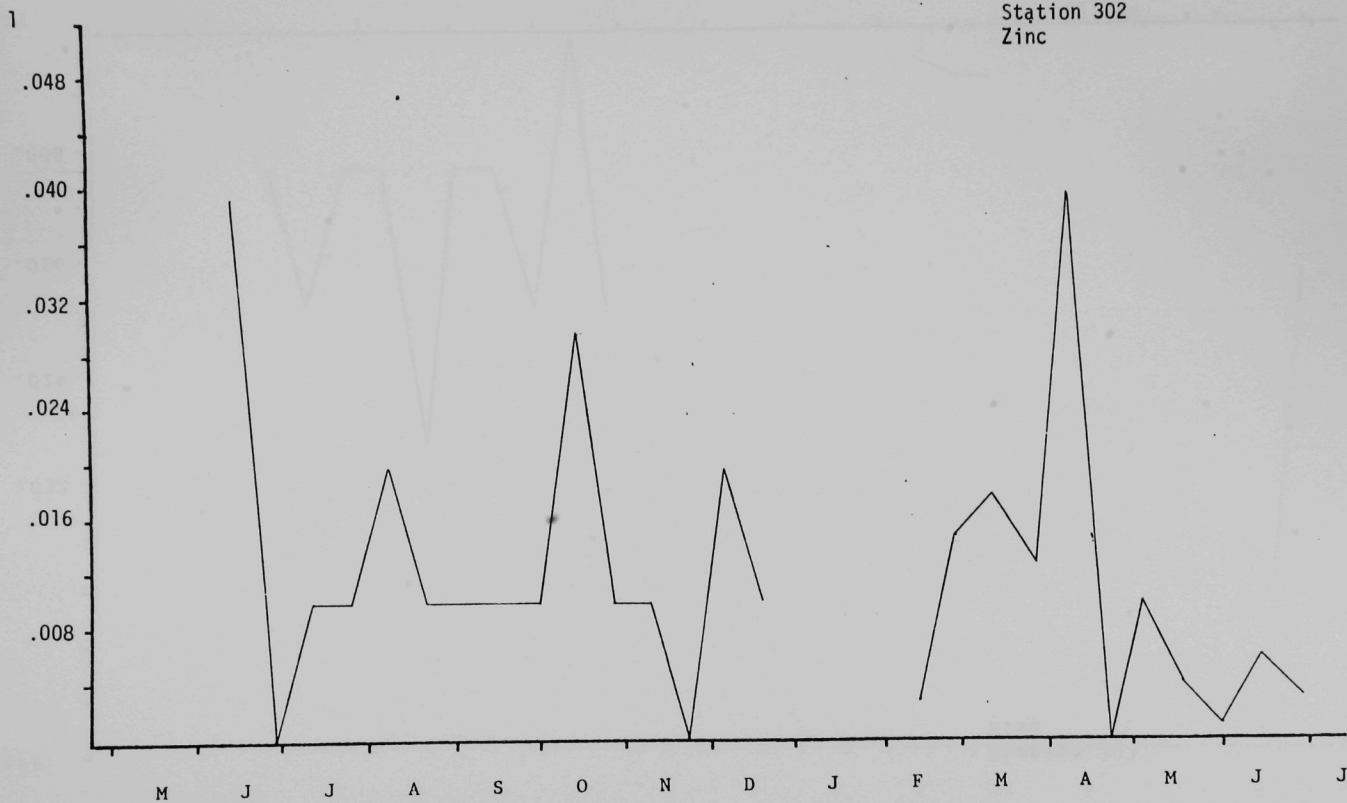
mg/l

Station 301

Zinc

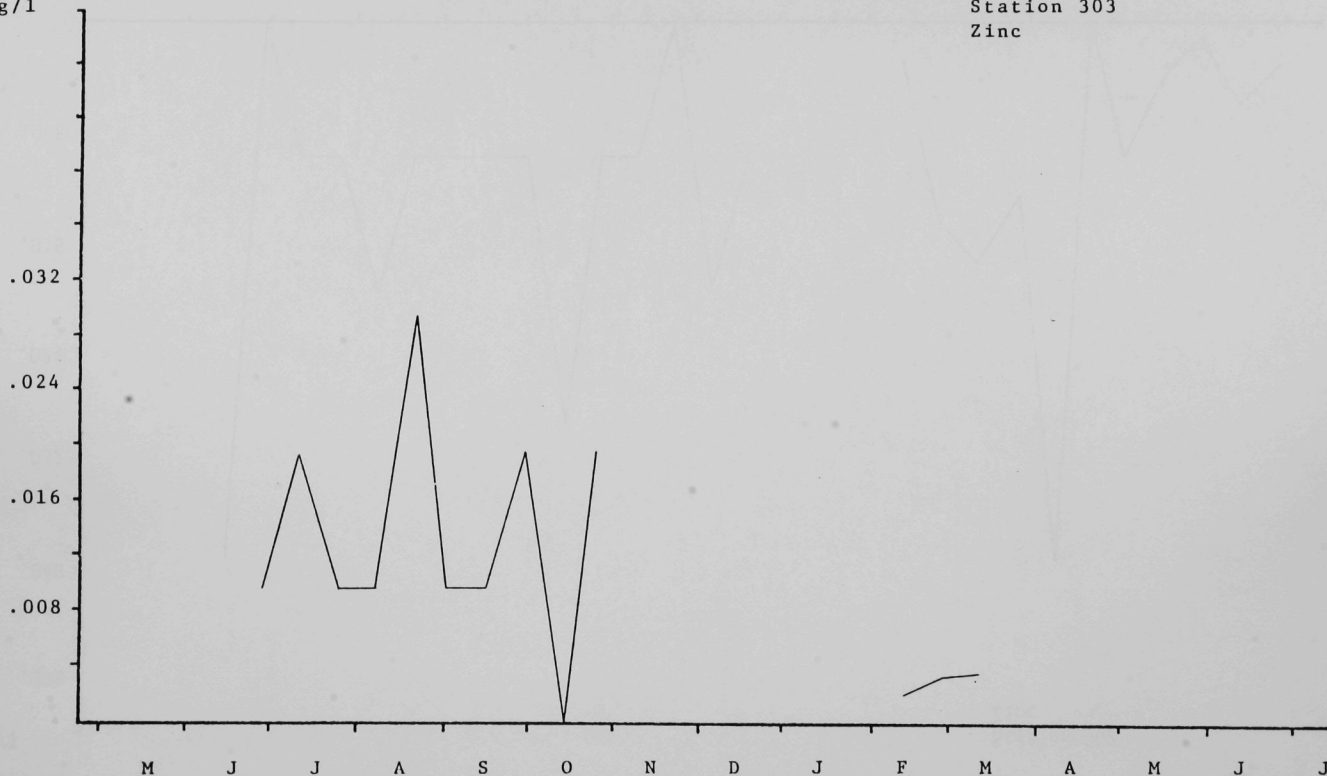


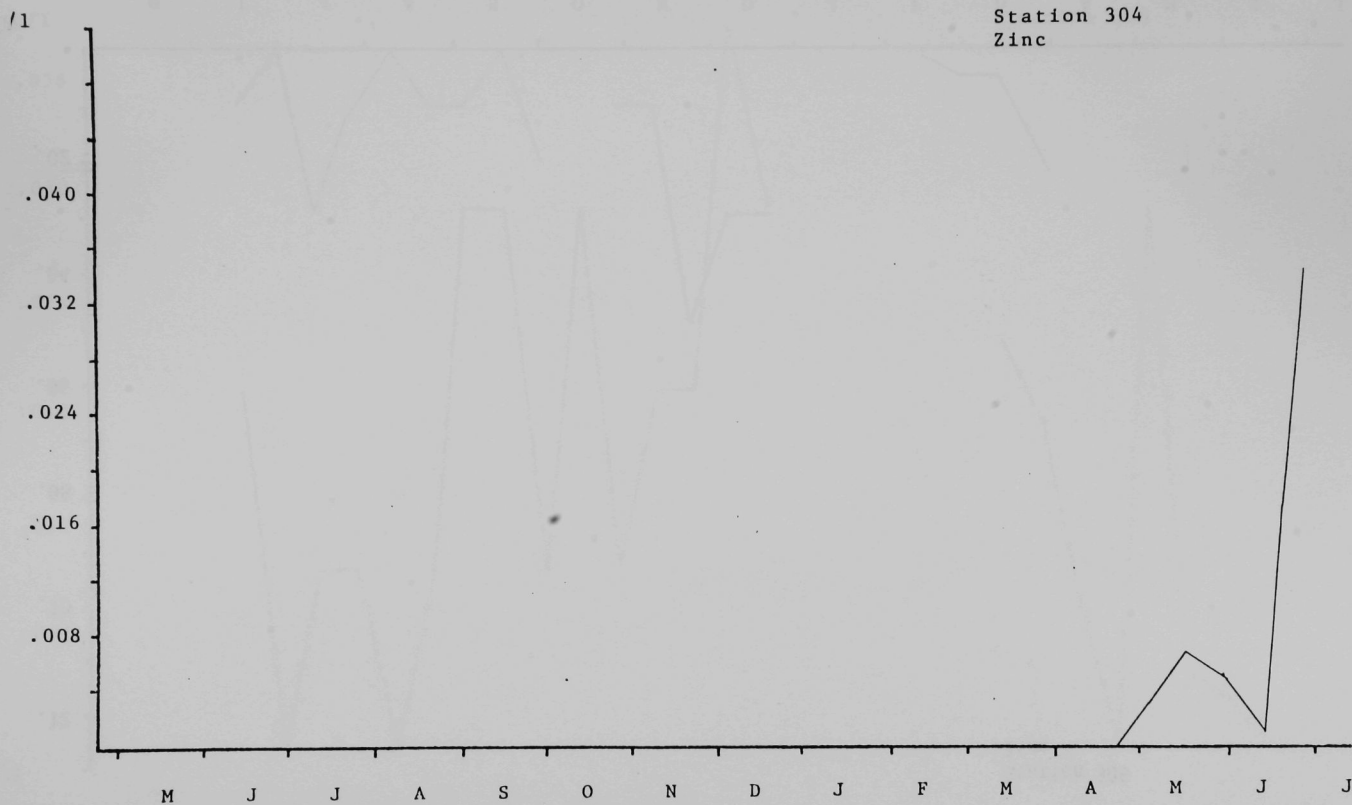
Station 302
Zinc



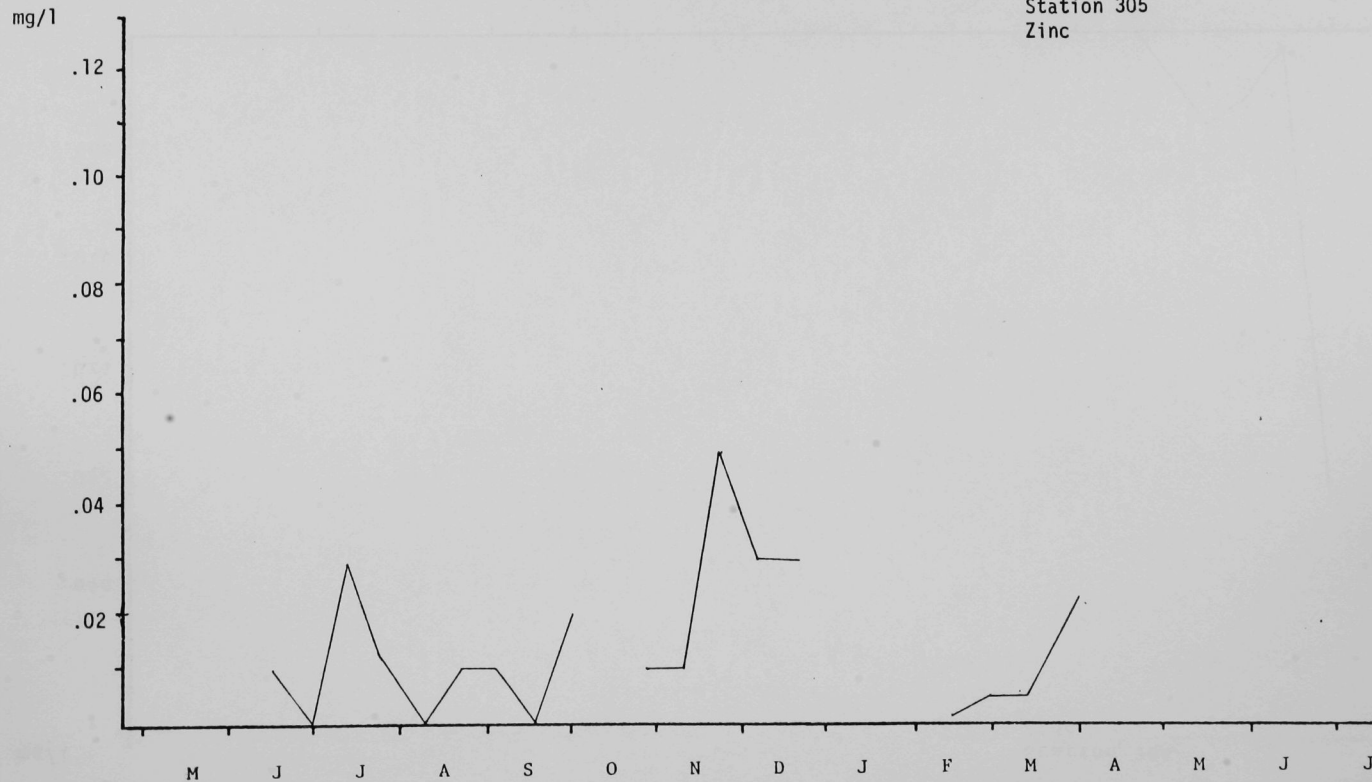
mg/l

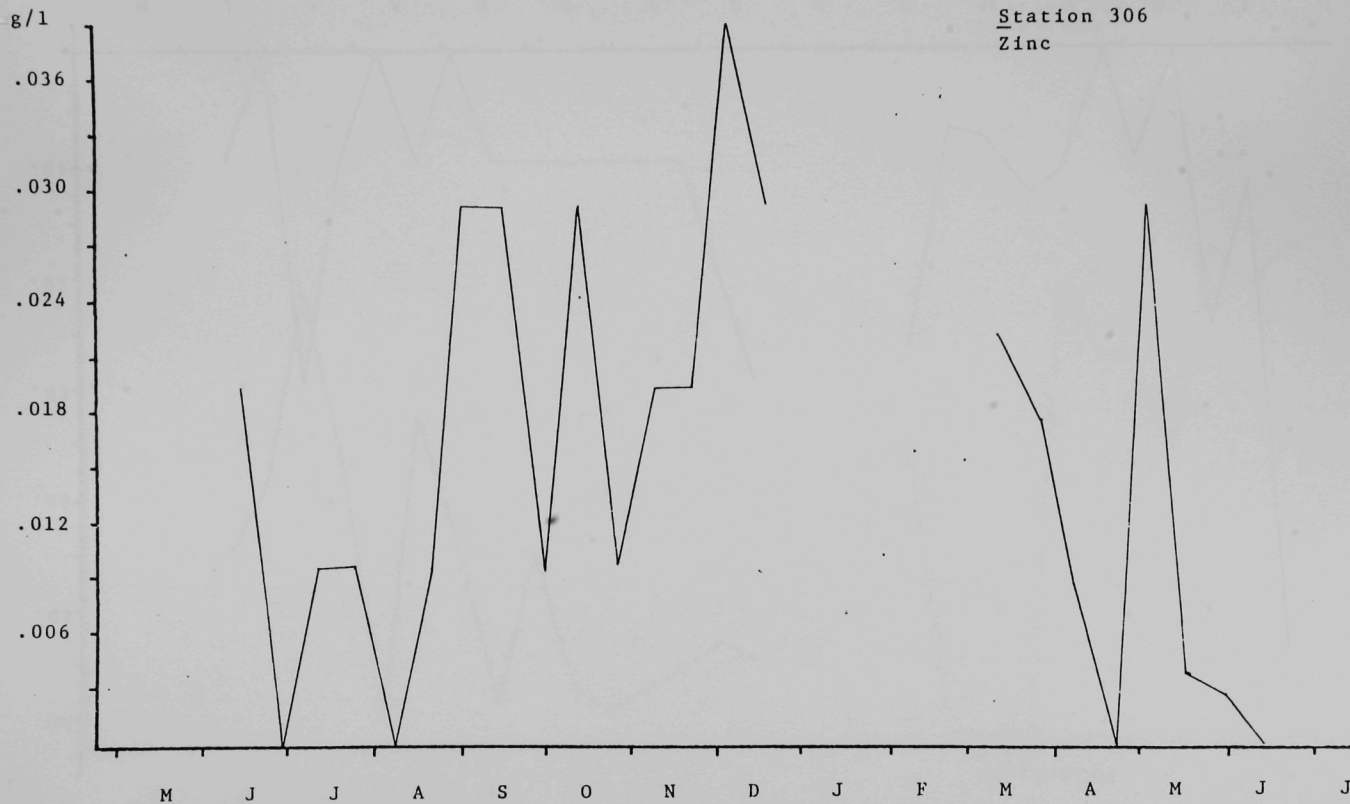
Station 303
Zinc





Station 305
Zinc





Station 307
Zinc

Month	Zinc (mg/l)
M	0.00
J	0.010
J	0.029
A	0.010
S	0.010
O	0.010
N	0.010
D	0.029
J	0.00
F	0.026
M	0.008
A	0.013
M	0.010
J	0.024
J	0.054

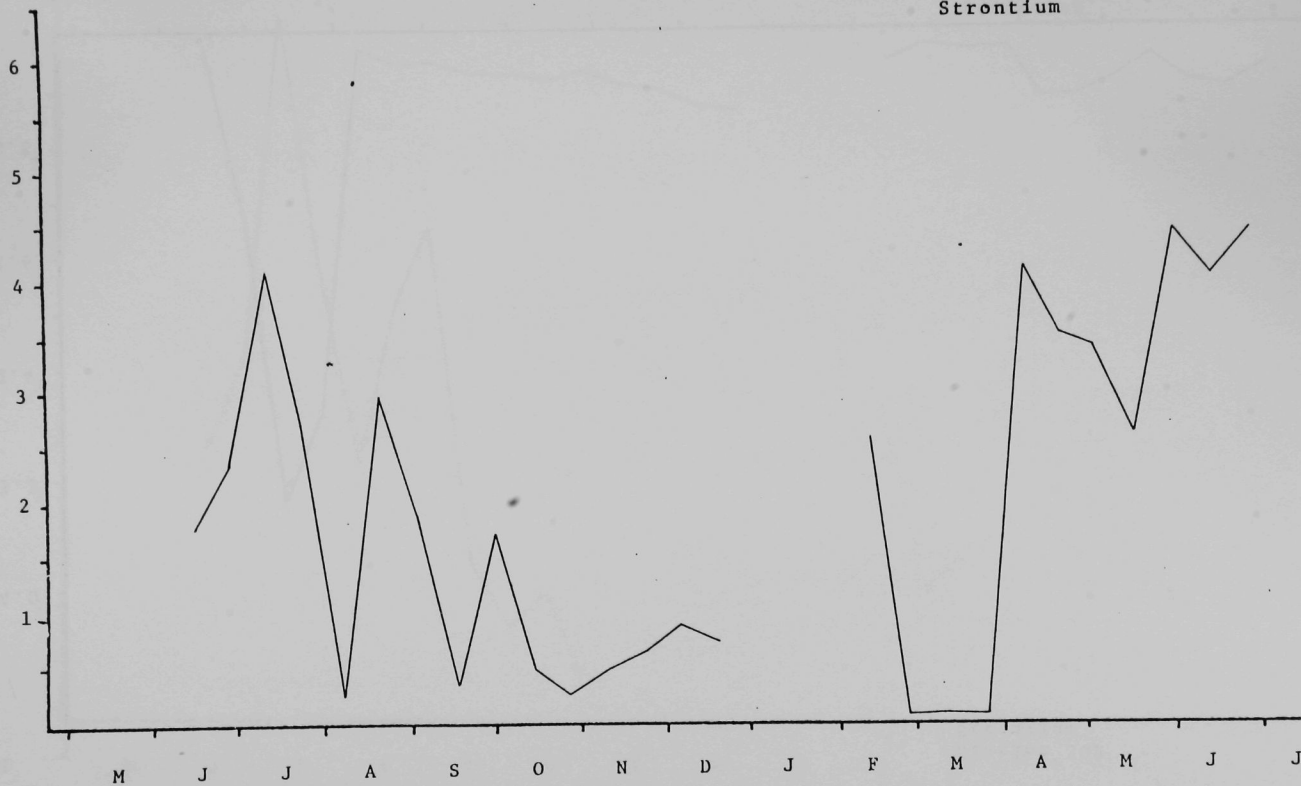
Station 307
Zinc

Month	Zinc (mg/l)
M	0.00
J	0.010
J	0.029
A	0.010
S	0.010
O	0.010
N	0.010
D	0.029
J	0.00
F	0.026
M	0.008
A	0.013
M	0.010
J	0.024
J	0.054

Station 307
Zinc

Month	Zinc (mg/l)
M	0.00
J	0.010
J	0.029
A	0.010
S	0.010
O	0.010
N	0.010
D	0.029
J	0.00
F	0.026
M	0.008
A	0.013
M	0.010
J	0.024
J	0.054

Station 301
Strontium



mg/l

Station 302
Strontium

4.0

3.2

2.4

1.6

0.8

M

J

J

A

S

O

N

D

J

F

M

A

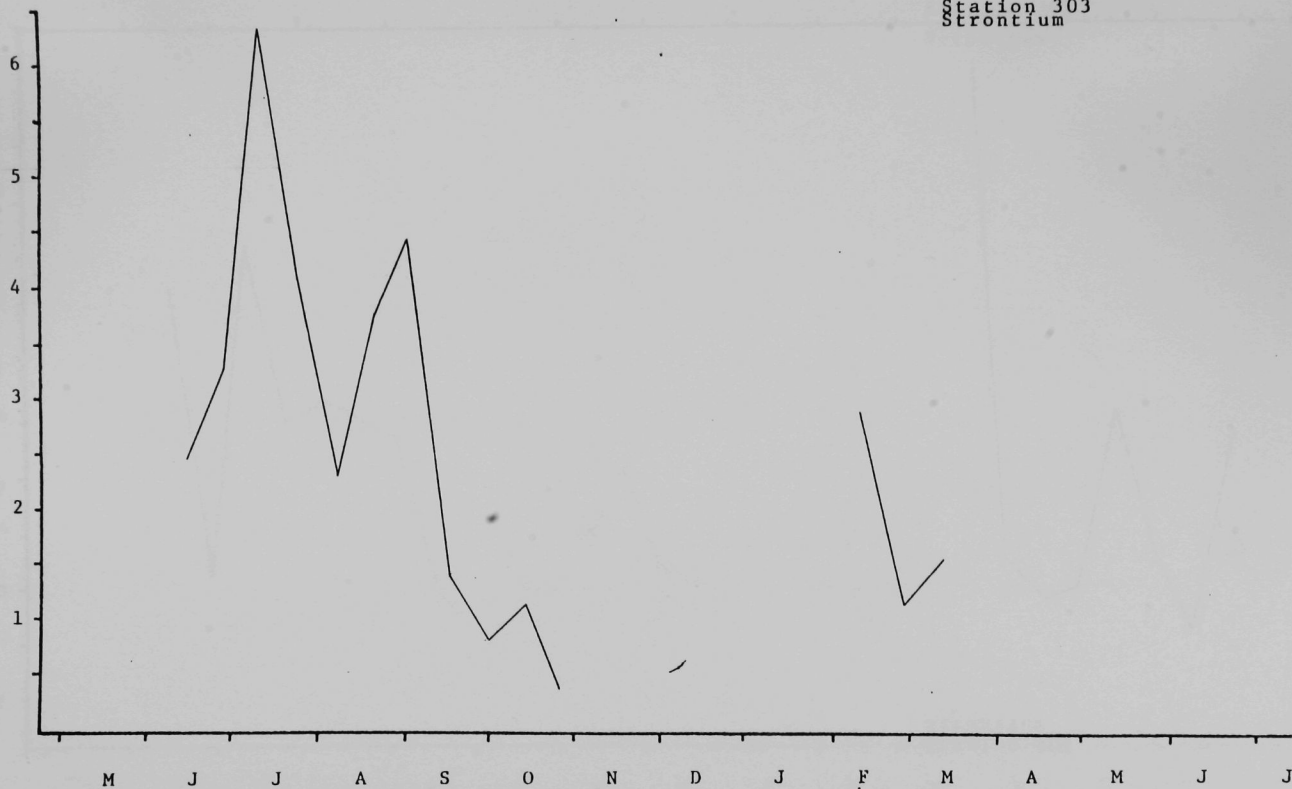
M

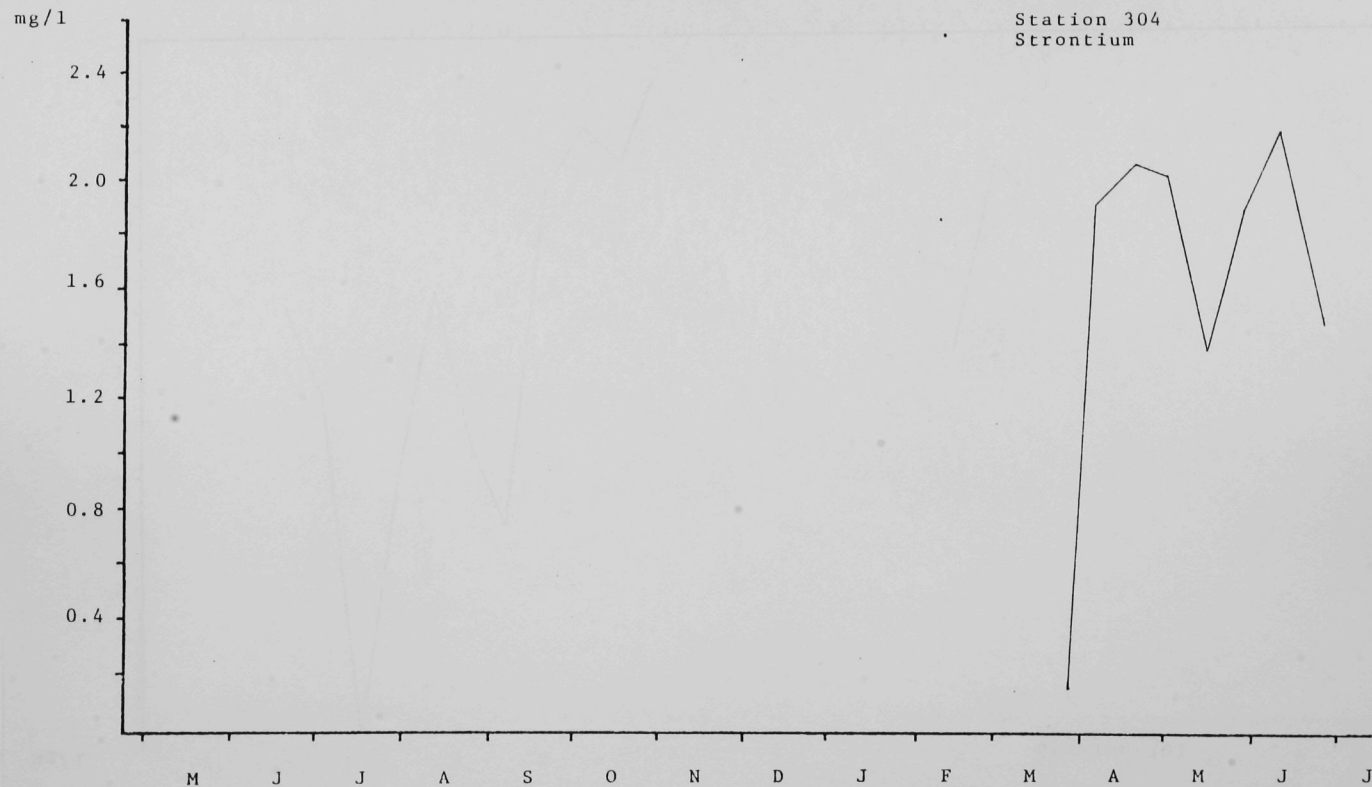
J

J

/1

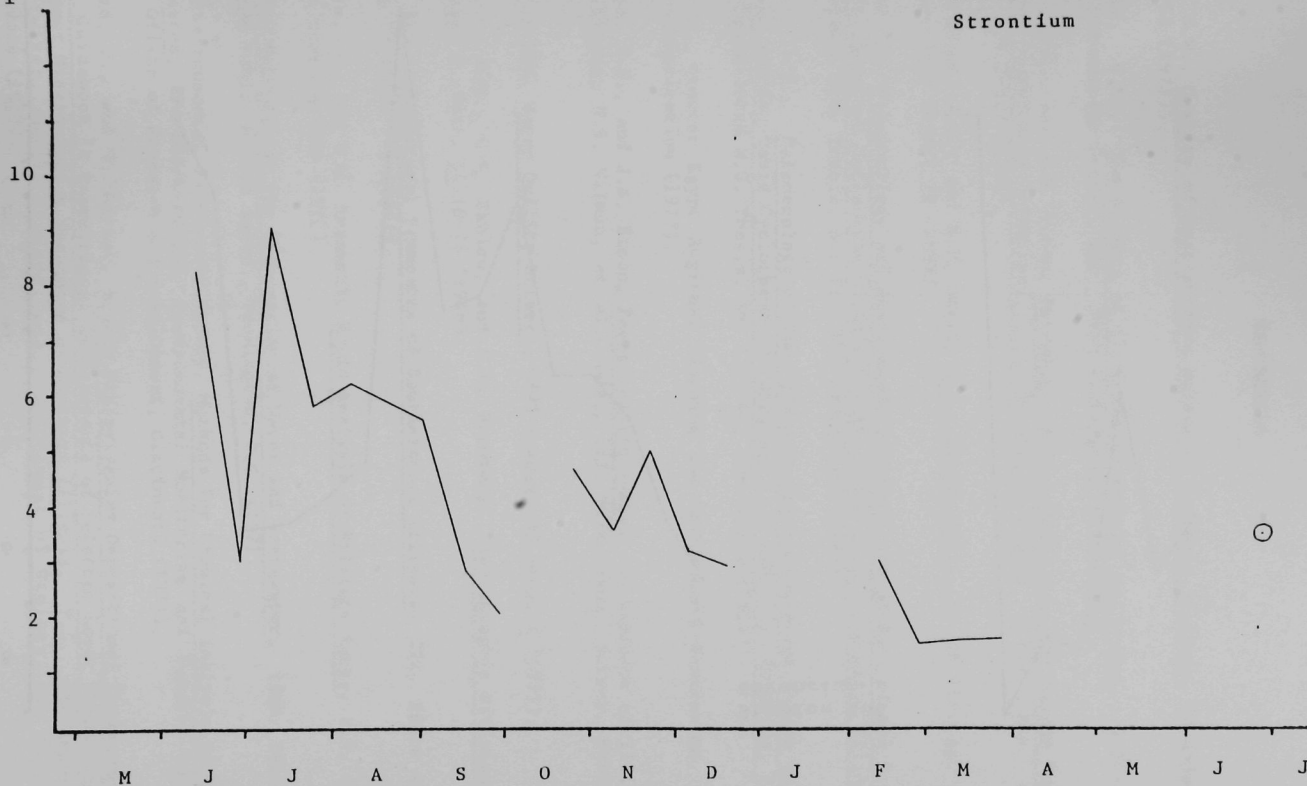
Station 303
Strontium





g/l

Station 305
Strontium



mg/l

7.8

6.6

5.4

4.2

3.0

1.8

0.6

Station 306
Strontium

M

J

J

A

S

O

N

D

J

F

M

A

M

J

J

222

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